NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

CREATING FEEDBACK CHANNELS WITH OPTICAL COMMUNICATIONS FOR INFORMATION OPERATIONS (IO)

by

Stephen K. Phillips

June 2016

Thesis Advisor: Don Brutzman
Co-Advisor: Ed Fisher

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704–0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2016	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE CREATING FEEDBACK CHANNELS WITH OPTICAL COMMUNICATIONS FOR INFORMATION OPERATIONS (IO)			**5. FUNDING NUMBERS**
6. AUTHOR Stephen K. Phillips			
7. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N/A____.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT

Current efforts within Information Operations (IO) to effectively measure the influence and performance of products used to message primarily human target audiences lack the benefits that web-based analytic technologies can provide. This thesis adapts previous research dedicated to optical communications through Quick Response (QR) codes as a messaging platform to provide a feedback channel for IO messaging efforts through optical communications technology. First, these concepts are applied to show covert amphibious operations. Optical communications technologies, direct marketing principles, and current IO shortfalls are explored to determine whether optical communications technologies can provide feedback channels for IO. The results are an integration of the analytic techniques used by Internet advertising campaigns incorporated into the continuous Observe, Orient, Decide, Act (OODA) loop decision-making process of IO practitioners. Integration of cyber-related analytic techniques offers IO practitioners a larger set of tools to measure message delivery accuracy and gain feedback on product effects directly from target audiences. This research recommends exploration of applications of cyber-related capabilities associated with QR code scanning to provide empirical proof of concept feasibility. The benefit of cyber-related analytic tools is an increase in ability to accurately measure effectiveness and performance for Information Operations.

14. SUBJECT TERMS Information Operations, IO, QR code, optical communications, direct marketing, measure of effectiveness, MOE, measure of performance, MOP, enhanced MOP, feedback, feedback channels, OODA loop			**15. NUMBER OF PAGES** 141
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01-280-5500 Standard Form 298 (Rev. 2–89)
Prescribed by ANSI Std. 239–18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

CREATING FEEDBACK CHANNELS WITH OPTICAL COMMUNICATIONS FOR INFORMATION OPERATIONS (IO)

Stephen K. Phillips
Captain, United States Marine Corps
B.S., United States Naval Academy, 2010

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION WARFARE SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 2016

Approved by: Don Brutzman, Ph.D.
Thesis Advisor

Ed Fisher
Co-Advisor

Dan Boger, Ph.D.
Chair, Department of Information Sciences

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Current efforts within Information Operations (IO) to effectively measure the influence and performance of products used to message primarily human target audiences lack the benefits that web-based analytic technologies can provide. This thesis adapts previous research dedicated to optical communications through Quick Response (QR) codes as a messaging platform to provide a feedback channel for IO messaging efforts through optical communications technology. First, these concepts are applied to show covert amphibious operations. Optical communications technologies, direct marketing principles, and current IO shortfalls are explored to determine whether optical communications technologies can provide feedback channels for IO. The results are an integration of the analytic techniques used by Internet advertising campaigns incorporated into the continuous Observe, Orient, Decide, Act (OODA) loop decision-making process of IO practitioners. Integration of cyber-related analytic techniques offers IO practitioners a larger set of tools to measure message delivery accuracy and gain feedback on product effects directly from target audiences. This research recommends exploration of applications of cyber-related capabilities associated with QR code scanning to provide empirical proof of concept feasibility. The benefit of cyber-related analytic tools is an increase in ability to accurately measure effectiveness and performance for Information Operations.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

BLT	Battalion Landing Team
CMO	Civil Military Operations
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research (http://www.nps.edu/research/cruser)
DOD	Department of Defense
DVR	Digital Video Recorder
EBO	Effects-Based Operations
EMCON	Emissions Control
EMMW	ElectroMagnetic Maneuver Warfare
EMS	Electromagnetic Spectrum
EW	Electronic Warfare
HA/DR	Humanitarian Aid and Disaster Relief
HDR	Humanitarian Daily Ration
HERO	Hazards of Electromagnetic Radiation to Ordinance
HF	High Frequency
HUMINT	Human Intelligence
IFFN	Identify Friendly, Foe, or Neutral
IA	Information Assurance
IO	Information Operations
IP	Internet Protocol
IT	Information Technology
IW	Information Warfare
IRC	Information-Related Capabilities
ISAF	International Security Assistance Force
JEMSO	Joint Electromagnetic Spectrum Operations
KLE	Key Leader Engagement
LCAC	Landing Craft Air Cushion
LCVP	Landing Craft, Vehicle, Personnel
LED	Light-Emitting Diode
Li-Fi	Light Fidelity

LOS	Line-of-Sight
MAC	Media Access Control
MCWP	Marine Corps Warfighting Publication
MEU	Marine Expeditionary Unit
MILDEC	Military Deception
MISO	Military Information Support Operations
MOE	Measure of Effectiveness
MOP	Measure of Performance
NATO	North Atlantic Treaty Organization
NOW	Network Optional Warfare
NPS	Naval Postgraduate School
OCO	Offensive Cyber Operations
OODA	Observe, Orient, Decide, Act
OPSEC	Operational Security
OWC	Optical Wireless Communication
PA	Public Affairs
PII	Personally Identifiable Information
QR	Quick Response
RDT&E	Research Development Testing & Evaluation
RF	Radio Frequency
RFC	Request for Comments
RFI	Request for Information
SAVAGE	Scenario Authoring and Visualization for Advanced Graphical Environments
SIGINT	Signals Intelligence
SMS	Short Message Service
SNR	Signal-to-Noise Ratio
SOP	Standard Operating Procedure
SQL	Standard Query Language
SQRC	Secure Quick Response Code
SSID	Service Set Identifier
STO	Special Technical Operations

TA	Target Audience
TTP	Tactics, Techniques, And Procedures
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UN	United Nations
URL	Uniform Resource Locator
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
UUID	Universally Unique Identifier
VHF	Very High Frequency
WIW	Warfare Innovation Workshop

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

This thesis would not have been possible without the patience of my advisor, Dr. Don Brutzman. Without his guidance, I would have been lost in organizing and designing this thesis. I would like to thank my co-advisor, Ed Fisher, for his incredible contributions, insight and help throughout the process. Finally, I would like to thank Steve Iatrou for his valuable input with many key items central to the IO subject.

THIS PAGE INTENTIONALLY LEFT BLANK

I. CHALLENGES, MOTIVATION, AND APPROACH

A. INTRODUCTION

The ability to operate within the information environment is essential to successful military campaigns, yet it presents a difficult and unique set of issues when conducting communications among friendly units during the full range of military operations. The average military officer immediately thinks of communications in the traditional context of information being transmitted via the radio frequency (RF) portion of the electromagnetic spectrum (EMS), where data is sent via traditional analog means or with an analogy signal modulated to represent the 1's and 0's of digital values. Communications are essentially one-way or unidirectional, but most often communications will elicit a response from the party receiving the information.

Since all wireless communications transmit over the electromagnetic spectrum, and most modern communications use wireless means at some stage, many vulnerabilities and limitations result from the use of this medium. First, access to the EMS has the potential to be interrupted or jammed, thus denying the use of this medium for communications. Second, when electromagnetic emissions are required to be controlled or eliminated altogether in order to avoid detection, then communications become severely limited. Severely restricted or unavailable communications retard the ability of forces to operate in unison as well as command and control of those forces.

Communications are integral to command and control and are thus one of the six Warfighting Functions of the Marine Corps (U.S. Marine Corps, 2005). There is, however, the optical channel for communications that has a two-way or bidirectional capability to both send and receive required information. Historically, this channel has been utilized through flashing lights, flag semaphore, or other relatively slow mechanical means. Recent research has provided a potential for employment of Quick Response (QR) codes and, alternatively, digital flashing light (DFL) as new means for sending and receiving communications covertly in the open.

Similar to command and control, within IO it can be especially difficult to effectively communicate to a target audience. There are many tools and products used to communicate to target audiences; however, the majority of these methods that do not involve direct contact are one-way. Given the unidirectional nature of most targeting tools and products, forces do not have the ability to directly elicit a response from the recipient in order to quickly measure the message's effectiveness and enhanced performance in achieving the desired behavior. Concern arises when a message has the potential to achieve a specific behavior from the target audience but ends up producing a behavior that is different from the one intended, causing negative effects to the greater military operations. This concern leads to a need to measure these effects and performance early and often, in order to get ahead of the unintended effects. If friendly forces can measure the unintended effects early and often, then it is possible to produce messages and themes to manage the unintended effects as well as address the second-order and third-order unforeseen effects.

At the core, advertising and marketing campaigns are simply campaigns for influence over a population that attempt to achieve a specific response, usually through viewership or the purchase of a product. Traditionally, these occurred by identifying mediums that the audience frequently used and placing ads in these mediums with the hope that members of the desired audience see the advertisement and are influenced sufficiently to purchase the product. For example, Nike has a new basketball shoe being released and places an ad within the sports pages of a newspaper or in a popular sports magazine in anticipation that the readers will see the ad and later purchase the shoe. The effectiveness of these ads can only be measured indirectly through the increase in the number of sales made, which came via the customer physically entering a retail store and buying the product. There may be a strong correlation between increased marketing and increased sales, but without further research, a direct relationship is not proven. Direct website marketing revolutionized the way advertising agencies were able to tailor ads to their intended audiences and achieve greater and more specific influence. A significant change that came with direct marketing was the ability to obtain instantaneous feedback from the audience that the advertisement reached, creating a two-way communication

channel via the Internet. This thesis open the door to similar impacts, effectiveness, and performance becoming possible for IO through the use of QR code links to Internet-based information, allowing a full OODA loop to become possible where currently only broadcast messaging is utilized.

B. PROBLEM STATEMENT

The information environment, which includes the human brain, is complex and non-quantitative by the nature of the cognitive aspect of human decision making. This complexity makes the observation of desired effects especially difficult when the target audience of an IO message is a specific person or population. IO currently falls short in its ability to quickly and qualitatively provide feedback regarding the influence a particular message has on its target audience. Furthermore, there is a lack of application in IO of web-based feedback techniques currently used by direct marketing in the private sector. More capabilities are needed to accomplish IO effectively.

C. MOTIVATION AND PURPOSE

When examining the two-way optical channels that DFL and QR codes provide, it appears that a new audience-feedback channel for IO influence can be achieved. Using QR codes for communications to and from a target audience can provide a two-way medium for influence that includes deeper messaging and incorporates ways to gain feedback more quickly and accurately. Coupling this concept with appropriate direct marketing techniques used by advertising agencies can potentially allow for quicker measures of effectiveness (MOEs) and measures of performance (MOPs), thus leading to better tailored, more effective and efficient messaging within IO. The establishment of QR codes or other similar technology as links for a two-way medium for influence and messaging can provide IO practitioners a new and effective capability. IO messaging changes from a send-only broadcast-style effort to audience-directed feedback and a full-fledged OODA loop.

D. RESEARCH QUESTIONS AND HYPOTHESIS

1. Research Questions

- How can Line-of-Sight (LOS) optical communication channels be established, in the absence of radio frequency communications, for ship-to-objective amphibious operations in order to demonstrate two-way communication?
- How can a direct feedback loop from target audience to IO-planned messaging be established?
- How can a direct feedback loop from target audience to IO-planned messaging help measure the target audience's response to message?
- How can a direct feedback loop assist in evaluation of measures of effectiveness and performance?

2. Hypothesis

Previous concepts established through optical communication channels for amphibious operations using DFL and QR codes can lead to a potential follow-on application for a direct feedback loop increasing evaluation capabilities for IO messaging. If the direct feedback loop can be established, then appropriate direct marketing web-based evaluation practices can be applied to IO practices and the ability to observe MOEs and MOPs will increase.

E. METHODOLOGY

This research first examines the challenges of communications in a contested environment and provides motivation for a new method of optical communication to be used in order to demonstrate the potential of two-way communications provided by optical communications. Previous research has validated the ability to use QR codes as a means of optical communication. Current research is ongoing with higher quality optical devices in the maritime environment. Scenarios will demonstrate the need, as well as how the optical communications channel can provide a tactical advantage in both Emissions Control (EMCON) limited Amphibious Operations and within IO. A study of how advertising and marketing were revolutionized by the feedback loop provided by direct marketing will be conducted in order to analyze the methods for potential application to

IO. The ability to link QR codes as an optical communications channel that utilizes two-way communication for IO messaging towards target audiences are explored in detail. No field experimentation has yet been conducted.

F. THESIS ORGANIZATION

This thesis first explores the concept of optical communications for amphibious operations while offering a two-way channel for landing craft and amphibious ships to communicate from ship-to-shore as a means to illustrate the two-way communications capability provided. It then explores the concept of two-way communication with other technologies beyond DFL and optics, such as QR codes scanned by a target audience's cellphone or tablet. Finally, it explores the interaction of target audiences and IO practitioners' decision-making process, and presents direct marketing practices to provide more information on the target audience's reaction via a feedback loop. Profound relationships and changes for IO are beginning to emerge.

Chapter II lays the baseline of knowledge for the proceeding chapters by referencing previous works on QR codes, as well as studying different areas of potential application. Two Naval Postgraduate School theses focused research on the technical and the tactical use of QR codes as digital semaphore for the U.S. Navy's ships as a means of EMCOM communications. This chapter also synopsizes the baseline of knowledge to understand IO's basic principles, and takes a quick look at Edward A. Smith's idea of effects based approaches to operations.

Chapter III focuses on the application of optical communications and their capabilities. It examines DFL and then provides a more in-depth look at the applications, capabilities, and technical side of QR codes. The chapter also provides a vignette using an amphibious landing scenario. Chapter IV analyzes the revolution that occurred in advertising and marketing when direct marketing techniques began to grab the attention of major corporations. Chapter V explores how to achieve the feedback channel for IO by discussing current shortfalls, providing examples and a vignette, and finally examining Boyd's Observe, Orient, Decide, Act (OODA) loop from an IO perspective. Finally, Chapter VI concludes the thesis with recommendations and opportunities for future work.

The appendices offer the reader several resources that are beneficial for the comprehension of IO Information-Related Capabilities (IRC) and QR code basic concepts and principles. Appendix A provides an adaptation of the definitions of the IRC from Joint Publication 3–13, *Information* Operations, in order to provide the reader with a succinct overview of the IRC. Appendix B provides the Wikipedia QR code page as a reference, which is accurate as of the date in this thesis. Appendix C is a QR code flyer from the Network Optional Warfare (NOW) NPS Wiki page.

G. BENEFITS OF STUDY

The goal of this thesis will be to examine the application of optical communication during an amphibious operation in order to apply the identified benefits and characteristics to optical communication, web-based analytic, feedback channels for IO. This will lead to the idea of a two-way communication channel that is outside the RF portion of the EMS and can provide other potential military force applications. QR codes will be presented as one possible platform for two-way communications with target audiences. This platform will be presented in conjunction with an examination of current IO doctrine and tactics in order to improve the effectiveness and performance measuring of information-based influence on target audiences through communications channels utilizing a two-way communication concept as a method to create a feedback loop.

Additionally, IO practitioners can benefit from the study of advertising and marketing agencies' web-based techniques used in direct marketing. This can lead to advances and integration of cyber capabilities that can thoroughly benefit the intelligence process, targeting, MOEs and MOPs for IO campaigns.

The ultimate benefit will be to provide IO practitioners with a new application and concept for more immediate feedback to messaging MOEs and MOPs. However, there will still be limitations within less technologically developed operating environments. Important recommendations regarding potential future effectiveness and performance measures of IO are expected.

II. DOCTRINE AND RELATED WORKS

A. OVERVIEW

This chapter will focus on the previous work dedicated to discovering optical communication channels beyond DFL and flag semaphore. Two theses have researched and written on the subject of digital semaphore, with one focusing on the tactical implications of QR codes used for optical communications and the other on the technical aspects of QR codes and the optical channel they present. Both theses combined efforts for experimentation with basic optics and QR code processing. The concepts of IO will be presented so that the reader will possess a basic understanding of the complexities presented by the information environment as well as the difficultly in measuring messaging effects and performance. Effects-based operations (EBO) will be addressed specifically in regards to the complexity of these operations. Finally, the chapter will conclude with the problem description.

B. INFORMATION OPERATIONS (IO)

Just as the Industrial Revolution changed the mechanics of how the world operated within business, warfare, and everyday life, the advancements within information technology has also changed the way the world operates. These advances have ushered in the "Information Age" which can be characterized by

> the widespread proliferation of emerging information and communication technologies and the capabilities that those technologies provide and will provide humankind to overcome the barriers imposed on communications by time, distance, and location and the limits and constraints inherent in human capacities to process information and make decisions. (Alberts, 1997, p. 2)

If the world has in fact entered into the Information Age, then this means an embarkation "on a journey in which information and communications will become the dominant forces in defining and shaping human actions, interactions, activities and institutions" (Alberts, 1997, p. 2).

Since the expansion of information technology has led to a new era within the world, then warfare must also enter a new era, IO or Information Warfare (IW) as the Marine Corps refers to it. Joint Publication 3–13, Information Operations, defines IO as "the integrated employment, during military operations, of Information-Related Capabilities in concert with other lines of operation to influence, disrupt, corrupt, or usurp the decision making of adversaries and potential adversaries while protecting our own" (U.S. Joint Chiefs of Staff, 2012, p. 84). Within the DOD's doctrine for IO, the definition of the information environment is as, "the information environment is the aggregate of individuals, organizations, and systems that collect, process, disseminate, or act on information" which consists of three separate but related dimensions; the *physical*, *information*, and *cognitive* (U.S. Joint Chiefs of Staff, 2012, p. 18).

1. Physical Dimension

Joint Publication 3–13 defines the physical dimension to be "composed of command and control (C2) systems, key decision makers, and supporting infrastructure that enable individuals and organizations to create effects" (U.S. Joint Chiefs of Staff. 2012, p. 19). It is seen as the actual physical environment in which these platforms and people interact. Joint Publication 3–13 states that "the physical dimension includes, but is not limited to, human beings, C2 facilities, newspapers, books, microwave towers, computer processing units, laptops, smartphones, tablet computers, or any other object that is subject to empirical measurement" (U.S. Joint Chiefs of Staff. 2012, p. 19). Figure 3 summarizes the physical to be "Tangible, Real World." This is traditionally where military leadership applies tactics, fight battles, and measure the success of a campaign or operation, hence the key terminology of empirical measurement.

2. Information Dimension

As Figure 3 shows, the information dimension is best represented as Data-Centric (U.S. Joint Chiefs of Staff, 2012). Joint Publication 3–13 describes it as encompassing "where and how information is collected, processed, stored, disseminated, and protected. It is the dimension where the C2 of military forces is exercised and where the commander's intent is conveyed. Actions in this dimension affect the content and flow of

information" (U.S. Joint Chiefs of Staff. 2012, p. 20). This dimension really can be seen as the link of how data or information is transmitted between the participants or audiences.

3. Cognitive Dimension

As was quoted earlier by Alberts (1997) in reference to the Information Age, the information is targeted at the "human capacities to process information and make decisions" or in other words, the cognitive dimension (p. 2). According to Joint Publication 3–13, Information Operations, "the cognitive dimension encompasses the minds of those who transmit, receive, and respond to or act on information" (U.S. Joint Chiefs of Staff. 2012, p. 20). How people receive and respond to information is drastically different between groups and individuals. The factors that can shape the reception and response to information can range from emotions, upbringing, culture, education, mental stability, religious beliefs, and even chemical imbalances within the person. This shows the complexity of the cognitive dimension, and thus is why defining these "factors in a given environment is critical for understanding how to best influence the mind of the decision maker or create the desired effect" (U.S. Joint Chiefs of Staff. 2012, p. 20). Due to this complexity and the fact that decisions are made in the cognitive dimension, many will agree that this is the most important component of the information environment (U.S. Joint Chiefs of Staff. 2012).

Each dimension is influenced by and has influence on each of the other dimensions. Information flow can skip the physical dimension and make it straight into a human's brain via the direct connection from information dimension to the cognitive dimension, as shown in Figure 1. However, the flow of information can also be easily passed over the physical dimension before influencing the cognitive. Many other possible paths of information flow between the dimensions are possible. Figure 1 is the interaction of all three information dimensions per Joint Publication 3–13

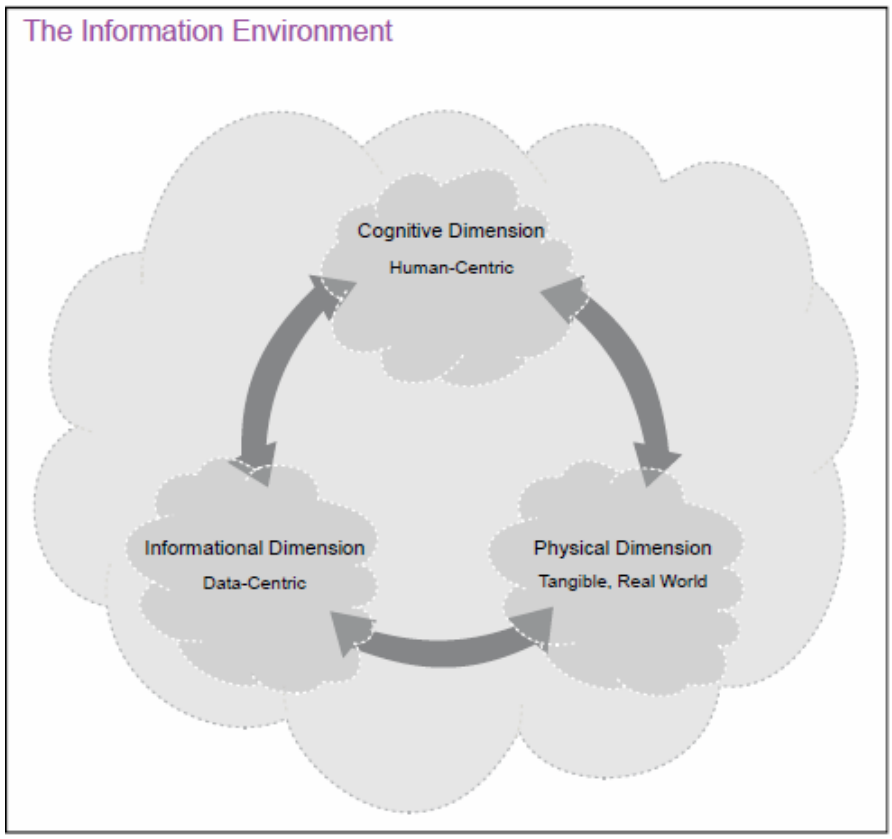


Figure 1. The Information Environment interacts between all dimensions in both directions. Source: U.S. Joint Chiefs of Staff. (2012).

4. Information-related Capabilities

IO is the coordination of Information-Related Capabilities (IRC). Per Joint Publication 3–13, the IRC include, but are not limited to Strategic Communications, Joint Interagency Coordination, Public Affairs (PA), Civil-Military Operations (CMO), offensive and defensive Cyberspace Operations, Information Assurance (IA), Space Operations, Military Information Support Operations (MISO), Intelligence, Military Deceptions (MILDEC), Operational Security (OPSEC), Special Technical Operations (STO), Joint Electromagnetic Spectrum Operations (JEMSO) or Electronic Warfare (EW), and Key Leader Engagement (KLE). When the IRC are properly coordinated, they can complement one another without conflict and are able to then influence a target audience's access to, or perception of, information. Further descriptions of the IRC are listed in Appendix A.

5. Requirement for Measures of Effectiveness (MOEs) and Measures of Performance (MOPs)

In the DOD's Information Operations Directive, DoDD 3600.01, the policy for IO across all components of the DOD is defined. The directive states that "DOD IO programs and activities will incorporate an explicit means of assessing the results of operations in relation to expectations" (Department of Defense, 2013). This policy simply states that all IO activities need to have associated MOEs and MOPs. There is no issue with creating a MOE on paper, however, it has proven difficult for current IO practitioners to fully accomplish quantitative and qualitative means to assess the results. The fundamental root-cause difficulty is that without a meaningful way to measure target audience effects, no realistic or timely MOE are truly possible. While IO effects from certain IRCs are currently easier to measure, such as those for EW, others like MISO have a much more difficult time measuring their effects because their target is the complex human decision-making process, in the cognitive environment.

C. EFFECTS-BASED OPERATIONS (EBO)

Edward A. Smith's *Effects-Based Approach to Operations* describes very similar principles to those of IO. The idea is to focus on "a desired end result" or effect (Smith 2006, p. vi). Effects-based operations (EBO) are "coordinated sets of actions directed at shaping the behavior of friend, foe and neutral in peace, crisis, and war" and can be characterized by "a focus on the human dimension of competition and conflict; the consideration of a full spectrum of actions whether in peace, crisis, or hostilities; a multifaceted, whole-of-nation concept of power; and the recognition of the complex interconnected nature of the actors and challenges involved" (Smith, 2006, p. 95–96). Smith's major arguments for EBO are derived from the fact that decisions made during operations have many different possible outcomes, which do not necessarily follow a specific order, and thus can be incredibly difficult to predict whether the desired outcome will be achieved by one specific input. In his words, it is the "array of interdependent variables in which the chain of causes and effects between an action and an outcome will seldom if ever be the same, in which outputs are not proportionate to inputs" (p. xi).

Specifically, EBO is focused on four domains; *physical*, *information*, *cognitive*, and *social*. These domains obviously have a very similar connection to the dimensions of the information environments, with the added complexity of the social domain. The first three domains are what make up the action-reaction cycle or how actions effect the decisions of humans, which is depicted in the cognitive, information and physical domain boxes of Figure 2. The steps of the action-reaction cycle are sense-making, decision making, and execution. While the whole of the action-reaction cycle is important, Smith places significant importance upon the human influence of the domains within the cycle because "all effects-based approaches are ultimately about shaping human perceptions and behavior, and because they depend heavily on human beings to make the complex estimates and decisions involved" (Smith, 2006, p. ix). This is the cause for adding the social element on top of the existing domains of the information environments for EBO. Figure 2 shows the action-reaction cycle with the social domain added given by EBO.

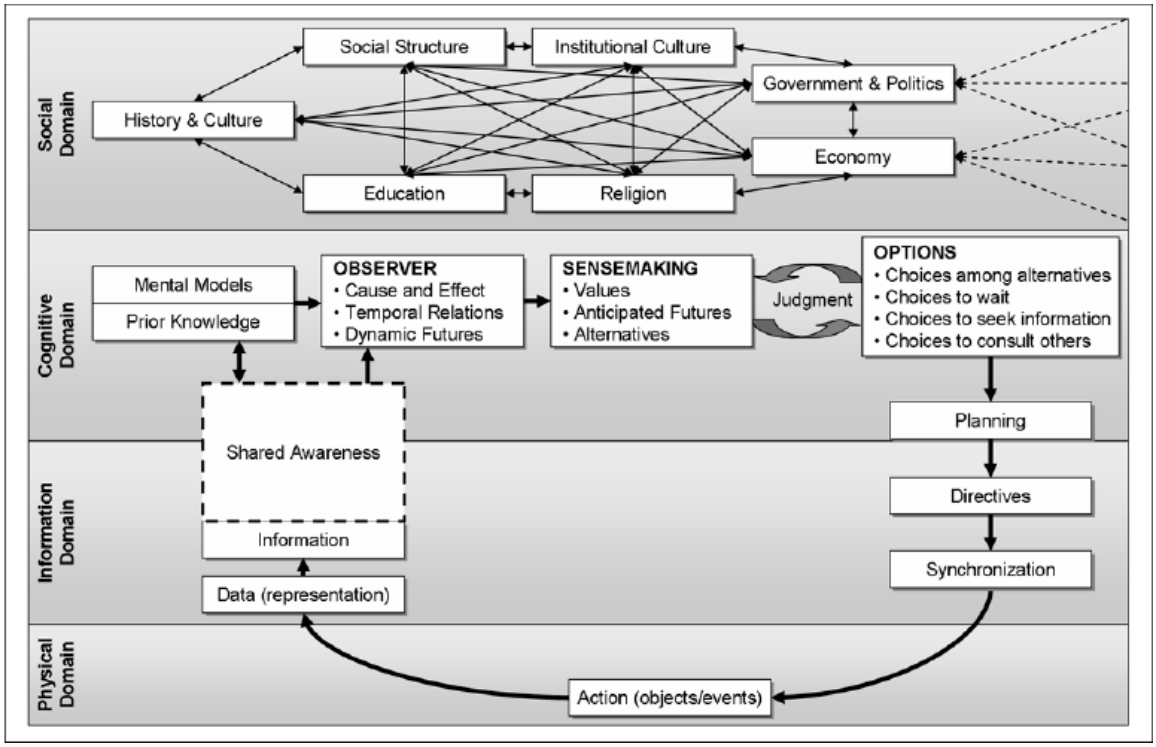


Figure 2. The Action-Reaction Cycle integrates the Social Domain for further complexity. Source: Smith (2006).

In order to implement EBO, the action-reaction cycle must be organized, or simplified, in a manner that the processes of assessment, planning, and execution can be placed into the hands of the military decision makers. The result that Smith (2006) created took the sense-making, decision making, and execution aspects and paired them with assessment, planning, and execution with influence from the social domain directly infusing into each step. The result is shown in Figure 3.

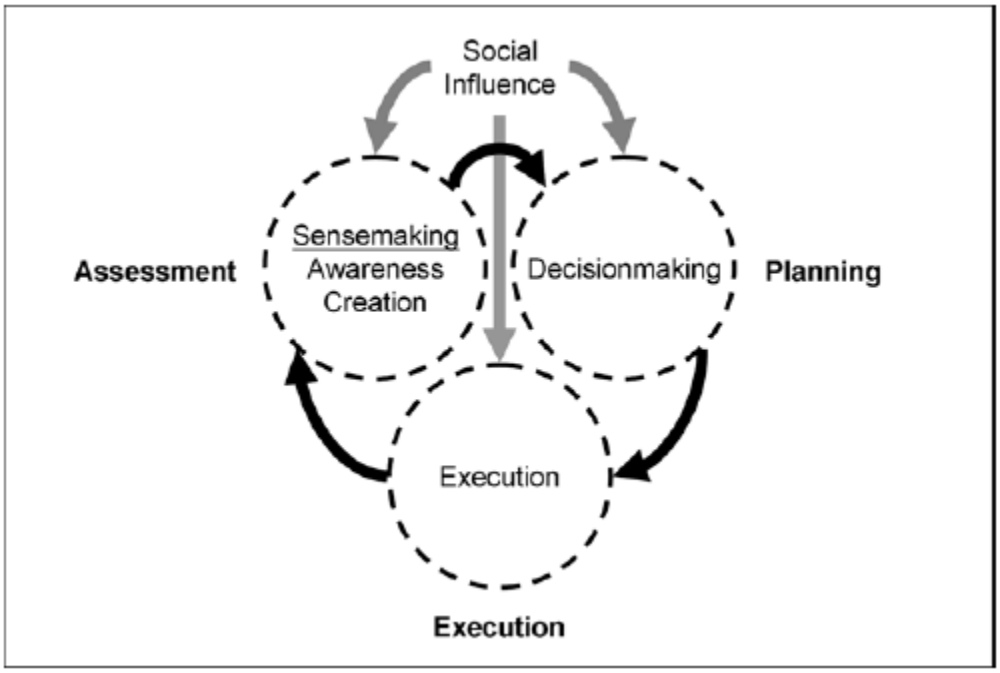


Figure 3. EBO Planning/Action-Reaction Cycle involves social influence. Source: Smith (2006).

The complexity of the cognitive environment and the importance of influence in this environment during military campaigns and operations leads to the question, how can military leadership create strategies and tasks for information operations? The purpose should not be to solve this complexity, but the answer is EBO. This is because "an effects-based approach is about maintaining a laser-like focus on the 'why' of a mission rather than a given approach or means to that end" (Smith, 2006, p. v). The concept of EBO does not need to be executed perfectly, "only better than (the) opponents" (Smith, 2006, p. xv). When this same concept is applied to the OODA loops in Chapter V, it is

associated to the notion of "getting inside the opponents OODA loop" and has fundamental value.

D. DIGITAL SEMAPHORE USING QUICK REACTION (QR) CODES

1. Overview

Line-of-sight (LOS) communication has been a critical element of all tactical operations within military history and even more so in modern military tactics with the shift to maneuver warfare and decentralized command. LOS communications are typically conceptualized by military leaders in current tactical environments through the EMS in the form of high frequency (HF), very high frequency (VHF), and ultra high frequency (UHF). The limitation of communications to this portion of the EMS is, however, not necessary. Basic hand and arm signals are taught to every Marine while learning fire team and squad tactics, which is a form of LOS communication that does not involve any detectable acoustic or RF signature. The use of flags onboard naval vessels to communicate between ships during underway replenishment is still a common practice, also known as flag semaphore. Additionally, light has been used throughout history as a form of signaling, seen in Figure 4. One of the most famous examples of the use of light signaling is documented through words of Henry Wadsworth Longfellow in the second stanza of his poem *Paul Revere's Ride*.

> He said to his friend, "If the British march
> By land or seas from the town to-night,
> Hang a lantern aloft in the belfry arch
> Of the North Church tower as a signal light, —
> One if by land, and two if by sea;
> And I on the opposite shore will be,
> Ready to ride and spread the alarm
> Through every Middlesex village and farm,
> For the country folk to be up and to arm."

Figure 4. Paul Revere's Ride is an example of early optical communications to spark a warning of imminent attack.
Source: Wikimedia Commons (n.d).

The story of Paul Revere's ride is commonly taught in the American school systems during primary education, yet despite early exposure to such concepts, the modern U.S. military as a whole rarely trains or plans to use simple concepts such as light signals. Rather military planners solely rely on complex technologies that are vulnerable to exploitation and counterattack. Communications utilizing HF, VHF, and UHF are

susceptible to detection and interception, as are optical communications, but more specifically they can be jammed so that the communications cannot be received.

The problem with the susceptible nature of radio frequencies (RF), like VHF, as a means for communications is that if it is in fact interfered with, the ability to conduct coordination between units and higher headquarters is severely limited or completely defeated. A potential workaround to RF interference was conceptualized by a team at Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Warfare Innovation Workshop (WIW) at the Naval Postgraduate School (NPS) in 2011. The team's solution adapted traditional flag semaphore and combined the use of QR codes to optically communicate. As Richter states, "the use of QR codes for visual communications has been coined Digital Semaphore" (2013, p. 1).

2. CRUSER

Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) is a research and education group at NPS, which is dedicated to developing technologies and solving problems with robotic and unmanned systems through innovation. The WIW in 2011 was "envisioned to provide a concept and/or mission thread to guide CRUSER research activities" (WIW, 2011, p. 3). The purpose of this WIW is further shown from the following paragraph.

> Concept generation is one of CRUSER's basic design tenets, and this workshop's primary goal. The mission directive given to the teams was to generate ideas and concepts for employing UxS in dangerous and dirty environments to accomplish specific missions. They were asked to emphasize current or programmed systems where incremental or evolutionary technical changes could have revolutionary operational effects. (WIW, 2011, p. 9)

During the CRUSER WIW in 2011, the concept of utilizing QR codes as digital semaphore to communicate outside of the RF portion of the EMS in a tactical environment was first presented. The team that provided this solution consisted of Army, Navy, and Marine Officers, along with engineers from the California Institute of Technology, the National Aeronautics and Space Administration Jet Propulsion Laboratory, and Space and Naval Warfare Systems Command Systems Center Pacific—

TEAM Piranha. They were given a specific set of problems to solve from a given military war-gaming scenario.

> TEAM Piranha's overarching intent was to compel the enemy to withdraw from the area without resorting to armed conflict in order to support freedom of mobility for U.S. and allied interests. Key factors the team considered in developing their strategy included geographic and overall strategic elements. The adversary armed asset sites given in the scenario provided area denial capability. (WIW, 2011, p. 22)

Within the team's presented scenario, they laid the following criteria for potential solutions:

> TEAM Piranha prefaced their concept generation with a discussion of solution criteria, proposing that any solution should minimize the risk of escalation and risk to U.S. personnel life. Concepts should also maximize use of existing technologies and retask or modify their capabilities. Finally, any concepts considered were evaluated using the following four factors: 1) Unmanned 2) Cost 3) Benefit 4) "Wow" factor. (WIW, 2011, p. 23)

QR code generation used to support digital semaphore was presented as part of the team's concept for support to direct operations. The idea they presented came from the desire to transmit communications passively over distance.

> Simple data matrices like quick response (QR) codes or bar codes can be displayed on digital screens (or use physical panels that flip over from white to black). The message recipient uses a high resolution camera (a satellite, airplane, UAV, etc.) to view the image and process the code into usable data. The message sender could be a semi-submersible UUV that can get to the surface but does not want to expose itself. The concept could also be used for sending messages between ships, ship to shore, shore to ship, etc.
>
> This concept's benefits include: a low observable signature because the message sender is not actively transmitting a signal, low power required because there is no active signal, potential for long range because it would only be limited by the camera's power, applicability to many platforms (e.g. UxS, ships, aircraft, satellites, shore sites, covert embedded assets, etc.), a relatively high data rate compared to many other passive communications systems, and it could be used not only in the visual spectrum, but also with IR if heated panels are used, or radar if panels with different radar reflectance are used.

> The drawbacks to this concept include: it is limited by environmental conditions such as line of sight, visibility, haze, clouds, dust, etc.; it is potentially difficult to receive a message from non-steady platform such as a USV at long distances; if two-way communications are desired, a high resolution camera on both platforms to receive messages is required. (WIW, 2011, p. 23–24)

Another CRUSER-sponsored workshop (Digital Semaphore, 2012) took the digital semaphore concept presented during WIW and showed proof of concept for the optical communications medium. As Lucas notes on the results of the CRUSER workshop, "increasing use of online and offline QR code creation applications in industry and the availability of digital storage allow users to find, encode and decode these two-dimensional barcodes with few barriers to success" (p. 18). While the workshop showed ease of processing the QR codes, it also identified that to operate within the complexities of a tactical environment, specific equipment and technology are needed for successful implementation (Digital Semaphore, 2012).

During the follow-on CRUSER work, two U.S. Naval Academy Midshipmen demonstrated the ability to quickly create and process QR codes through software developed by Mike Bailey and the Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE) Lab. This was the proof of concept for QR code streaming communication. The Midshipmen were able to type messages into the program, which then created a QR code and displayed that QR code onto a screen. The receiving party's laptop webcam captured the QR code's image from the screen and then the corresponding laptop decoded the QR code. The decoded QR code was displayed as text within a text chat window that the Midshipman then read. The Midshipman who received the first QR code was able to read the message, cognitively process the message and reply within the text chat window. The process was repeatable so that the Midshipman, who sent the first message, was then the receiver and a stream of optical communication between the two separated parties was established (Tactical QR Code Communication, n.d.).

The work done by the CRUSER workshops lead to the tactical and technical theses using QR codes for digital semaphore by NPS student, Richter and Lucas,

respectively. These two theses were done in collaboration together, thus much of the information presented by each overlaps.

3. Tactical Implications

Richter (2013) addressed the issue of providing the U.S. naval fleets with a new method of visual communications from ships to planes and UAVs at a tactical level in his master's thesis; *Digital Semaphore: Technical feasibility of QR code optical signaling for fleet communications*. This problem was addressed in order to enable forces to maintain operational effectiveness when emission control restrictions are imperative to mission success. Richter's thesis looked at related works on digital visual signaling through digital semaphore and provided a historical look at the importance of maritime communications and visual communications, including the methods by which these are accomplished. Electronic line-of-sight communications, to include UHF and VHF, were addressed by their advantages and disadvantages. In another chapter, Richter discussed the topic of emissions restrictions from emissions control to the effects of electromagnetic radiation on ordinance aboard ships and aircraft in order to add to the importance of non-electromagnetic means of communication. Richter's research methods and experimental results and analysis were discussed, as well as further recommendations for work were given, of which was that of "Capabilities Beyond Naval Applications."

An important part of Richter's argument formation is the historical use and effectiveness of visual signaling. The Battle of Trafalgar is used to "demonstrate the importance of visual communications in a time where radio frequency line-of-sight communications were not yet in existence" (Richter, 2013, p. 13). Admiral Horatio Nelson was able to maintain command and control of his fleet as well as communicate tactical maneuvering of his fleet in order to exploit weaknesses in the formations of the French fleet. Richter also uses World War II as an example of a period when radio communications were standard operating procedure (SOP) but visual communications were still utilized in the "event radio communications were destroyed due to the nature of the war" (p. 15). Richter concludes the section of history by demonstrating that the use of flag semaphore, flag hoist communications, and light communication have been effective

for the duration of their employment due to the simplicity of the methods coupled with simplicity of the required equipment. He also addresses the disadvantages of such signaling methods.

After conducting qualitative and quantitative analysis through simulations and field experimentation involving UAV QR code reading, Richter concluded that

> the results of this research show that there are numerous advantages to QR codes for communications in a tactical environment. QR code communication provides numerous advantages over traditional RF LOS communications. Since QR codes can be a visual method of communicating, there are nor RF emission, which greatly reduce the possibility of detection, intercept, and exploitation. (p. 115).

However, there were concerns that arose during experimentation. Movement of QR codes while sensing has yet to be tested and caused concerns as to the feasibility of processing. Additionally, due to experimental restraints on equipment, no detection past five hundred yards was achieved, however it is likely that detection can occur at multiple miles if higher quality equipment is used (Richter, 2013).

Richter visually depicts basic tactical scenarios for how QR code signals communication or digital semaphore can be used with an operational concept graphic, Figure 5. This graphic represents the ability for satellites, UAVs, aircraft, and ships to be able to maintain the line-of-sight needed to optically read the QR code images created from the information needed to be shared. The final link is satellite communication back to the secured headquarters outside the conflict zone.

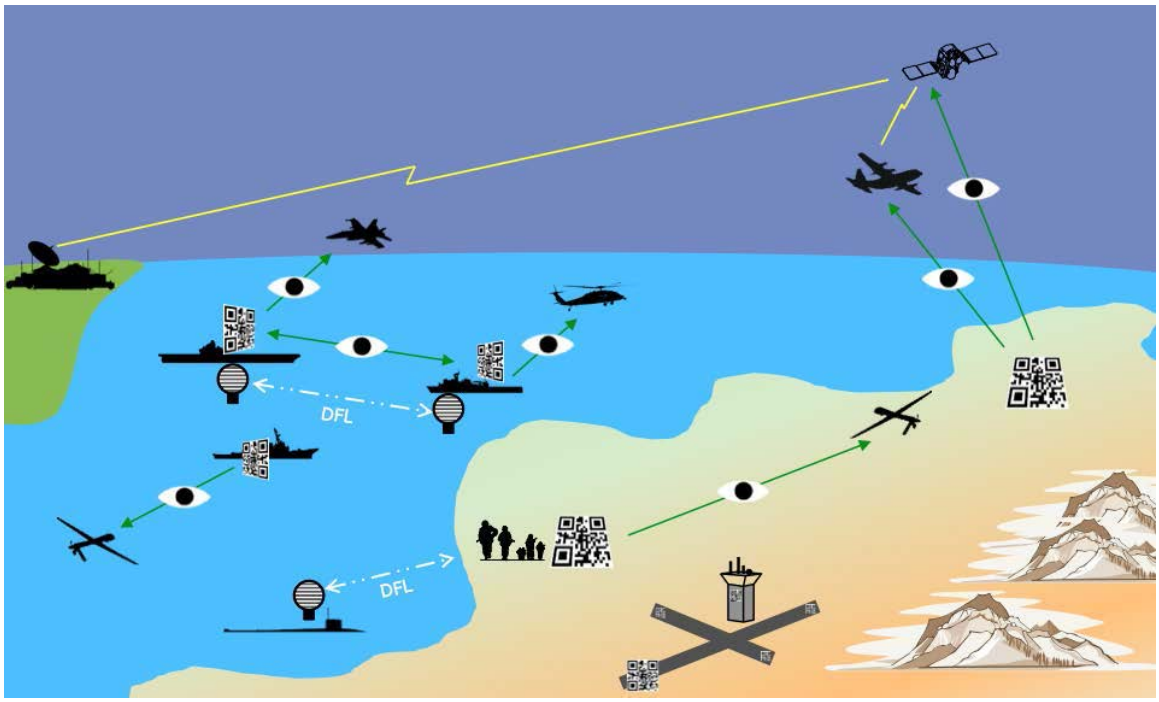


Figure 5. Operational concept graphic (OV-1 diagram) for the tactical implementation of QR codes as a visual communication method. The figure visually depicts that "QR codes allow emissions control to be achieved for a full range of in-theater fleet tactical operations." Source: Richter (2013).

4. Technical Feasibility

The technical side of Richter's thesis was examined by his classmate, Lucas, in the master's thesis titled "Digital Semaphore: Technical Feasibility of QR Code Optical Signaling for Fleet Communications." Where Richter analyzed the tactical side of using QR codes in signals communication, Lucas attacked the technical aspects of QR code design and processing. While this was the major focus of the thesis, Lucas also gave a brief overview of complications of radio line-of-sight as well as other forms of visual signaling.

Lucas broke down the history of barcodes, which are a one-dimensional and less complex visual data storage method that has been used much longer than QR codes. This laid the groundwork for the more complex two-dimensional QR code to be created. Lucas discusses the potential advantages and disadvantages of using QR code for tactical

communications while addressing the security concerns of displaying the code in the open. The benefits where that QR digital semaphore offers "communications between tactical units are more discrete, more difficult to jam, and can be conducted in an emissions-denied environment" as a quick and effective alternative to LOS voice communications (p. 2). The disadvantages showed that

> using QR code as a form of optical communication may be vulnerable to nonpermissible environments such as hazy conditions, fog, heavy seas, excessive background lighting or insufficient illumination. Unless exclusive equipment is used, any unencrypted transmissions may be vulnerable to intercept by an adversary. (Lucas, 2013, p. 3)

The signaling dataflow for QR codes to the receiving end of the line of communication was broken down into segments and explained. First, the data is input to a QR code creating program, and then the message is encoded where it is broken into segments. Those segments are then used to create the QR code image. That image is displayed within line-of-sight to the receiving party. The QR code image is captured and processed leading to the decoding of the message and output of the data (Lucas, 2013). Figure 6 shows this process and can be examined in more detail in both Lucas's thesis and in *Digital Semaphore*.

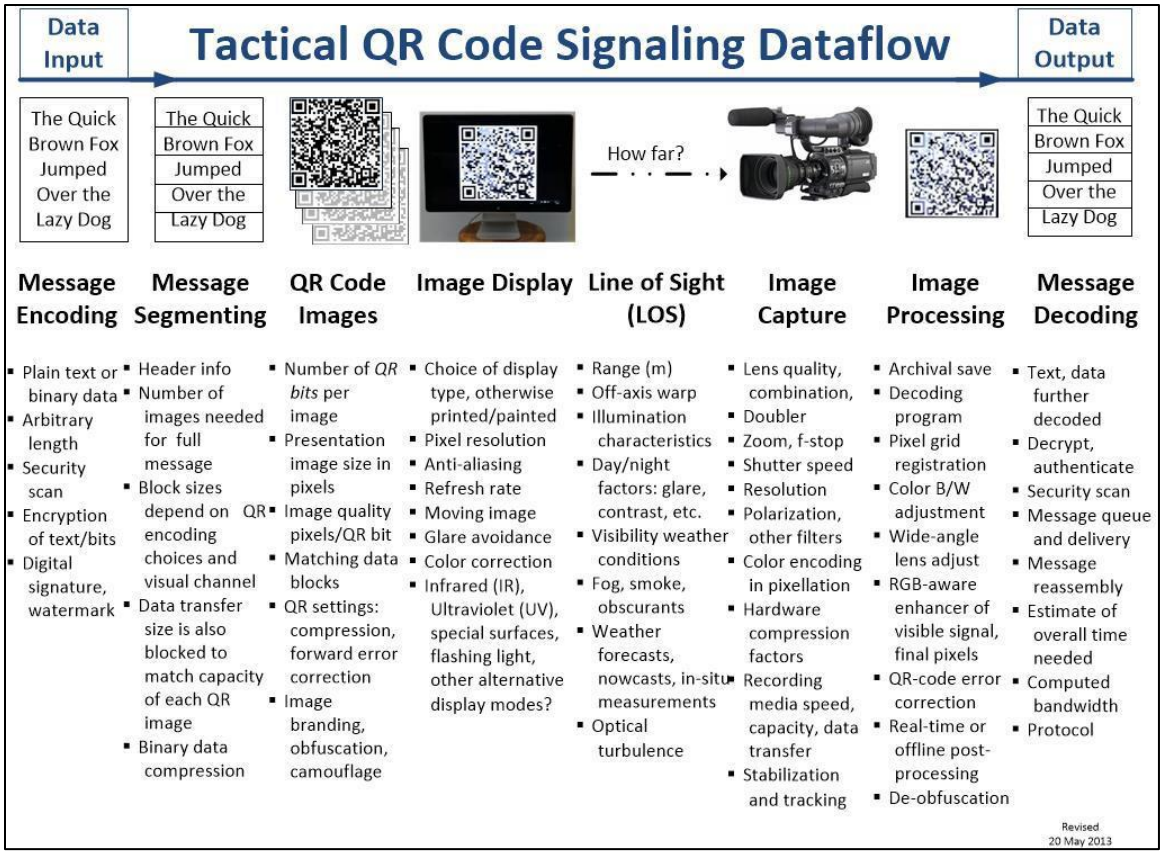


Figure 6. Ideal dataflow for a tactical QR code communications system considering end-to-end technology factors. Source: Digital Semaphore (2012).

Lucas worked jointly with Richter when it came to simulation and field experimentation. His objectives and measurements included maximum range capabilities, angular approach measurements of the UAV to the QR display, minimum size of the QR code display image, as well as actual QR code construction and reconstruction post sensing. One of Lucas's most significant findings was that if the QR code image taken by the UAV or satellite were to process the code after the fact rather than on the spot, the decoding performance drastically increased. From Lucas's technical approach to QR code application at a tactical level, he found that most QR codes are readable far enough away to make them relevant and that the optical resolution of the observing lens has the largest impact on the distance at which a QR code can be read (p. 85). Lucas also found that while these limitations in distance exist based on experimental constraints, the

introduction of software image-enhancement methods greatly increased maximum effective range of the capture.

E. NETWORK OPTIONAL WARFARE (NOW)

New technologies certainly enhance current military forces' ability to fight; however, the reliance upon these technologies creates major problems due to the need for networking capabilities for communications as previously discussed. The application of Network Optional Warfare (NOW) allows forces to avoid constant engagement in centralized communications. NOW is achievable "through efficient communications, signaling stealth, and deliberate tactical messaging" (Wyatt, 2016). U.S. Forces have the ability to operate in coordinated yet independent capacities (and have so for many years) but the reliance networking currently required to communicate and deconflict actions can become a critical vulnerable exploitable by adversaries. NOW identifies the vulnerabilities of constant communication due to dependence on the exchange of information and the lack of stealth, and offers as solutions the abilities of stealth, surprise, coherence, uncertainty, flexibility, scalability, autonomy and cyber (Wyatt, 2016). QR codes offer an essential tool to NOW operations. Appendix C shows NPS's NOW wikipage flyer on QR codes.

The NOW website includes numerous descriptions and references for Efficient Messaging, Optical Signaling, and Semantic Coherence. A blog further describes significant development in the evolution of this operational concept. The site can be found at https://wiki.nps.edu/display/NOW/Network+Optional+Warfare.

F. RELATED WORKS LINK TOGETHER

The research done to develop concepts for employment of newer technologies as optical communications lead to the concept of using QR codes to provide a better means to measure the effects and performance of IO messaging. The realization of the ability to communicate in two directions with optical communications lead to the idea of feedback as a form of measurement. QR codes are just one potential application that crosses multiple IRC making for enhanced means to assess results of operations in the Information Age.

G. SUMMARY

The birth of QR codes as an academic solution to EMCON conditions imposed upon naval forces in operational environments during the CRUSER workshop lead to the research done by both Lucas and Richter. The implication of naval forces being provided an optical communications channel has caught quite a few high ranking Naval Officers' attention. This research continues to be further developed, however it has also opened many other potential applications for QR codes. With current IO doctrine, there is a major lack of ability to elicit feedback from a target audience to better measure the effects of the message. The priority that has been placed on developing IO capabilities and its integration into the full range of military operations has led to the need for development of new means to measure the effectiveness of effects in the cognitive environment. EBO offers good perspective for the complexity and need for specific solutions to measure the effect. The chapters that follow show how all these areas can fit together to create new and important capabilities for IO.

THIS PAGE INTENTIONALLY LEFT BLANK

III. APPLYING OPTICAL COMMUNICATIONS CAPABILITIES

A. OVERVIEW

As has been outlined by both Lucas and Richter, as well as in previous chapters of this thesis, reliance upon communications through the RF portion of the EMS have become a critical vulnerability in military operations. The ability of adversary forces to intercept, jam, or deny RF communications severely limits and degrades the U.S. military's command and control of forces. Within certain operating environments, a historically effective solution can be utilized in order to solve RF communications vulnerabilities, visual light. The use of signal lights is not a new concept, but in fact has been used throughout history as a means of communication. The simplest implementation is lighting a fire or candle to signal the presence of the enemy, arrival of key elements, or any other singular communication of an event has been used throughout history. More recently, the coupling of the dots and dashes of Morris Code with light created a medium using signal lanterns or lamps where words were communicated without audible sound.

This chapter explores different means of communicating through optical channels that are outside of the RF portion of the EMS. Visible light is part of a different portion of the EMS that the human eye is capable of capturing. First, a look at Digital Flashing Light (DFL), a newer form of flashing light that leaves behind the need for fire or lanterns as light sources. Similar to DFL, is also the ability of using Light Fidelity (Li-Fi) Networking to provide more secure, less vulnerable channels via visual light communication (VLC). After DFL, a further step is taken in optical communications channels by applying the visual nature of QR codes and their capabilities. Finally, the potential value of these capabilities is illustrated in a vignette where an amphibious landing forces moves from ship-to-shore without RF communications.

B. DIGITAL FLASHING LIGHT (DFL)

1. Principles of DFL

In order to understand what DFL is, first an understanding of simple flashing light communication must be achieved. In 1843, Samuel F. B. Morse invented a new means to

transmit text-based messages, Morse code. Morse code originally defined each letter in the English alphabet by combinations of dots and dashes, which is able to be transmitted via telegraph, sounds, or flashing lights. These dots and dashes are translated into periods of exposure of light with a darkness, or obstruction, between the periods of exposed light, which can be seen by the human eye over LOS during low-light or darkness. The flashing light can sometimes be seen past the typical LOS distance if reflected off of clouds. Using the United States Navy (USN) as an example, the flashing light communication "started out utilizing lanterns which required fuel" but later "started using the arc-signal searchlight which had a quick-closing, venetian-blind shutter, which allowed signals to be sent quick" (Richter, 2013).

DFL differs from flashing light because it is not operated by a human who obstructs the light source to represent the breaks within Morse code that form and represent the message. It is instead the automated flashes of light that are a result of human language input into and information technology-based (IT) program that transmits and receives the message via a bit-derived programming language and then retranslates it to human-readable language. The flashes of light can mimic Morse code or bit communication via coding, i.e., ones and zeros. DFL cuts out the traditionally trained communicator who must know Morse code in order to transmit and receive the message.

2. Visual Light Communication (VLC)

VLC is a recent and seemingly more passive utilization of light to communicate. VLC is illumination plus communication; Illumination + Communication = VLC (Visual Light Communications, n.d.). The difference between DFL and VLC, as accepted by several authorities, is that VLC is constantly illuminating and not relatively slowly switching on and off repeatedly, but rather switching on/off or adjusting the dimness of the light at a frequency which the human eye cannot sense, in order to transfer the high bit-rate information from one party to another. The switching occurs at such a high frequency that it must be controlled by a computer, and that the communication cannot be deciphered except by a similarly high-speed receiving sensor, thus making the originator

look like strictly an illumination source to all other observers (Visual Light Communications, n.d.).

The ability to use VLC as a form of communication to send messages and data has come from the widespread development of light-emitting diode (LED) technology. LEDs are like silicon chips found in modern technology because they are semiconductors that can be switched on/off at high frequencies. This separates LEDs from regular fluorescent and incandescent light bulbs (Visual Light Communications, n.d.). LEDs offer more advantages over incandescent light bulbs as well; they emit more lumens per watt thus making them more energy efficient, they can be smaller in size with the same lumen output, they do not take the same amount of time to light up, they are able to be cycled due to the semiconductor nature and thus last longer, they do not heat up as drastically as other light sources, they are more durable in nature, and they can be designed to focus the light due to the flexibility in packaging (Using Light-Emitting Diodes, 2008). Due to these advantages, they have been developed for home and consumer use, which has led to a cheaper cost of production and advancement of capabilities. The time and research put into the development for energy efficiency has ultimately led to the opportunity for the development of VLC (Visual Light Communication, n.d.).

There are three other areas that are highly related to VLC: free-space optical communication, Li-Fi, and optical wireless communication (OWC). Li-Fi will be discussed later. Free-space optical communication is an expanded interpretation of VLC, in that it also includes ultraviolet and infrared wavelengths (Visual Light Communication, n.d.). Free-space optical communication is an area of development that can be further researched for limiting RF communications, as well as for benefits that are not available with visible light. For the most part, DFL and VLC are similar in employment and thus are referred to interchangeably when speaking of the employment of visual light sources for communications. Figure 7 shows the elementary concept of both DFL and VLC, with the exception of the flashing or blinking.

Figure 7. Digital Flashing Light (DFL) shows data flowing from light source to human interfacing platform. Source: Visible Light Communications (n.d.)

3. Advantages of Light-based Communications

First, the advantages of simple light communication are so significant that they are reiterated from Richter's thesis as to focus on the principles of light over RF first, and then DFL and VLC technological advantages are given. When comparing visible light to voice communication, which travels at the speed of sound, visible light is faster as it travels at the speed of light just as all electromagnetic waves travel. Morse code's universal employment and history make it a capable language for flashing light communication, but this can also be interpreted as a disadvantage. Light is not capable of being detected through the transmission of energy like RF can, which leads to the fact

that light is not capable of being jammed the same way that RF is. Unlike RF, which can be intercepted without the knowledge of its source, the directionality and maximum-range attributes of a light-based communication system must already be visibly detected prior to being able to intercept or eavesdrop on the transmission via LOS without obstructions (Richter, 2013).

When examining light-based communications technologies, such as VLC, as a form of data transfer, visible light offers many advantages as a supplementary technology to current mainstream RF communication technologies. By no means does one replace the other, but VLC serve as an compliment to the other in specific environments. This is because RF frequencies range from 3 kilohertz to 300 gigahertz, whereas visible light ranges from 430 terahertz to 750 terahertz. This offers a much larger range of available frequencies yielding greater bandwidth (Barney, Dich, & Koufos, 2014). The visible light range is approximately 10,000 times larger than the RF frequency range as can be seen in Figure 8 (Haas, 2013). The frequency range does not only benefit from larger bandwidth but also creates more space for less interference.

Within military environments, there are sensitive RF frequencies that can potentially cause unwanted detonation of munitions, Hazards of Electromagnetic Radiation to Ordinance (HERO), but the visible light frequencies do not cause damaging interference with the weapons systems that potentially can cause unwanted detonation (Richter, 2013). Similar considerations pertain for the natural emission of detectable signals from electricity traveling through wires in order to send communications; better known as Tempest. Outside of the military, there are vital technologies that are at risk of interference from RF transmissions that can result in functionally failure; hence, there are regulations guiding the use of RF frequencies in order to deconflict overlapping frequencies to avoid unintended jamming. (Barney, et al., 2014).

Another advantage offered is transferring data over the larger bandwidth results in the ability to bring faster transfer speeds to user devices. Since light sources are literally everywhere that electricity runs in the modern world, the abundance of platforms already exist and only require implementation of the programing concepts and technology (Barney, et al., 2014).

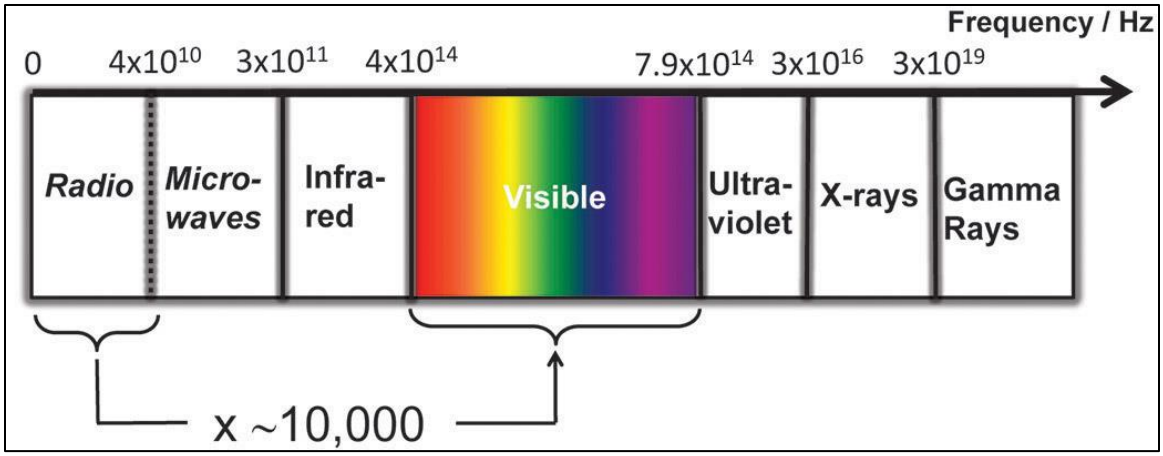


Figure 8. Electromagnetic spectrum (EMS) used to show the comparison of radio and visible light frequencies. According to Haas (2013),"the electromagnetic spectrum and the vast potential of unused, unregulated, safe green spectrum in the visible light part. The visible light spectrum is 10,000 times larger than the entire radiofrequency spectrum" (p. 1). Source: Haas (2013).

4. Disadvantages of Light-based Communications

Presented disadvantages first look at the specifics of the general disadvantages of light before looking at the disadvantages of technology-based light communications. With Morse code's universal employment, the use of this code language with flashing light or digital flashing light affords the ability for an adversary to intercept and translate the message if captured within LOS. Along the same lines, the recipient must be in LOS of the transmitting light (Richter, 2013). This leads to the disadvantage of requiring a LOS without any obstruction, as an obstruction leads to the inability to receive portions of the message. If an intermediate portion of a message is missed, there might be no way to know that a portion was missed without human cognition. Even so, in some cases this can be problematic. For example, if the message "do not launch the missile" with the preamble and indication of the conclusion of the message is transmitted, but the intermediate portion, "do not," is not received and only "launch the missile" is observed then the operator does not know that they are supposed to refrain and will take the message as a direct order to launch. Thus, message-integrity techniques must be included as part of optical communications.

The necessity to be close to boresight and within LOS of the light source can be seen both as an advantage and as a disadvantage. The inability for the visual light frequencies to propagate through any opaque and solid limits the application and situation for which it can be used. However, such a constraint can be considered a benefit rather than a limitation when applied correctly. For example, when transferring data a security benefit does arise. Eavesdropping is no longer a potential threat, and the data can be quickly and directly transferred from one device to another. Another example might be within a non-secure environment, when sensitive information can still be easily transferred from one computer, tablet, or phone to another without interference with the wireless communication (assuming the room being used is not being visually recorded). Even within a closed room environment, VLC does have limitations based upon ambient light. This can create a low signal-to-noise (SNR) ratio, which will disrupt communications via the illuminated light communication source and the rest of the light within the room (Barney, et al., 2014).

5. Light Fidelity (Li-Fi) Networking

The advantages of VLC for optical communications compliment other forms of communication or potentially can even replace them. OWC currently offers the ability to free bandwidth within the RF spectrum by assuming most the data transfer traffic from wireless-fidelity (Wi-Fi) connections with technology such as Li-Fi where applicable. Li-Fi is "a bidirectional, high speed and fully networked wireless communication technology" that uses only visible and continuously illuminating light (Li-Fi is a bidirectional, high speed and fully networked wireless communication technology, n.d.). As stated by Dr. Haas, the first to coin the term Li-Fi, "lighting is a commodity that has been integrated in virtually every inhabited environment and sophisticated infrastructures already exist" (Haas, 2013). As the use of LED lighting systems become more widespread (for example, in office spaces and aboard transportation systems), the implementation of Li-Fi might offer massive cost savings in both installation and energy. With intensity-modulation techniques, the ability to imperceptibly transfer data remains even when the lights visibly appear to be off (Haas, 2013). As of 2013, data rates were achieved in excess of 1 GBps for white LEDs and 3.4 GBps with red-green-blue LEDs in

experimental lab conditions (Haas, 2013). Figure 9 shows a potential indoor Li-Fi environment and the application possibilities.

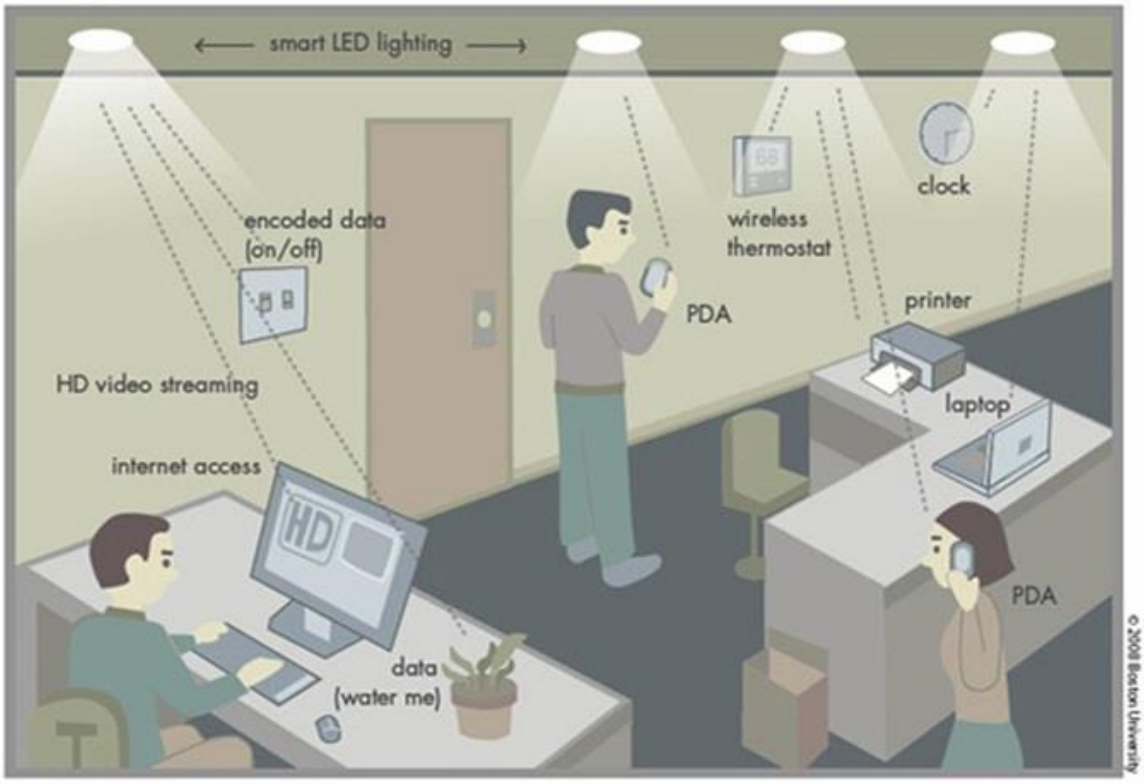


Figure 9. An example of people interacting in a Li-Fi capable environment through communications technology. Source: QRZnow.com (n.d.).

While Li-Fi's current research is focused on the relief of RF spectrum congestion, further research has the potential to lead to optical communication channels for the military. Research is being conducted on new ways to improve application for outdoor environments since the ambient light from the sun can cause lights of lesser intensity to have difficulty efficiently transferring data. Testing the potential for higher data speeds is also under study. One major potential use for higher data rates and ambient light resistant communications is with the downlink streaming of video feeds from UAVs. The vision for Li-Fi is to create a bidirectional connection not solely a one-way data stream (Tsonev, Videv, & Haas, 2013). This concept leads to a key concept in Chapter V: IO needs to have better bidirectional communication with target audiences.

C. QUICK RESPONSE (QR) CODES

1. Introduction

For this thesis, QR codes will serve the purpose of providing one solution to the typically unidirectional flow of information in regards to messaging within current IO practices. The QR code is an existing technology that has the ability to offer the bidirectional information flow via two parties displaying the QR codes to program information and visual communicate to each other or with the scanned QR code providing into a new web-based communications channel. It is not the only possible solution and may not even be the best solution, but it is currently the most developed and recognized of possible solutions. Research has previously been conducted by Lucas and Richter on QR code employment within optical communications, and this has led to QR codes becoming the chosen platform for this thesis. QR codes add several important factors; bit streams of arbitrary detail that are asynchronous, waiting for future reception at the right places, and at the right times.

QR code technology was originally developed by two individuals on a developmental team for DENSO WAVE, when users contacted them asking if it were possible to create barcodes that could code Kanji and Kana characters in addition to the already available capability for alphanumeric characters. The development team decided on a two dimensional system that had the potential to be scanned quickly, resulting in the QR code as we know it today (QRcode.com, n.d.). This technology received its first major acceptance when "adopted by the auto industry for use in their electronic Kanban" where it was applied for assembly line tasks from "production to shipping to issuing of transaction slips" (QRcode.com, n.d.). The technology has now been around for 22 years and is widely deployed, making it immediately available anywhere.

2. Principles

QR codes can be simply described as two-dimensional or more barcodes. Imagine a scenario where a customer purchases a prepackaged product from a store. The customer presents the item to the store employee operating the cash register. Instead of that employee having to know a single iota of information about the product being purchased,

the employee is able to scan the item over a group of sensing lasers and the price of the product is immediately displayed along with the barcode's labeling of that item for identification purposes. This is accomplished through a few bits of binary coding that are represented by the black and white strips, making up the barcode as seen on the right of Figure 10. Figure 10 also shows a QR code, on the left, and compares the two information-storing images for further understanding of the differences. In principle, QR codes operate the same way, only that that they are scanned in two directions rather than one. This second dimension allows for the storage of up to a thousand times more information than barcodes (QRcode.com, 2016).

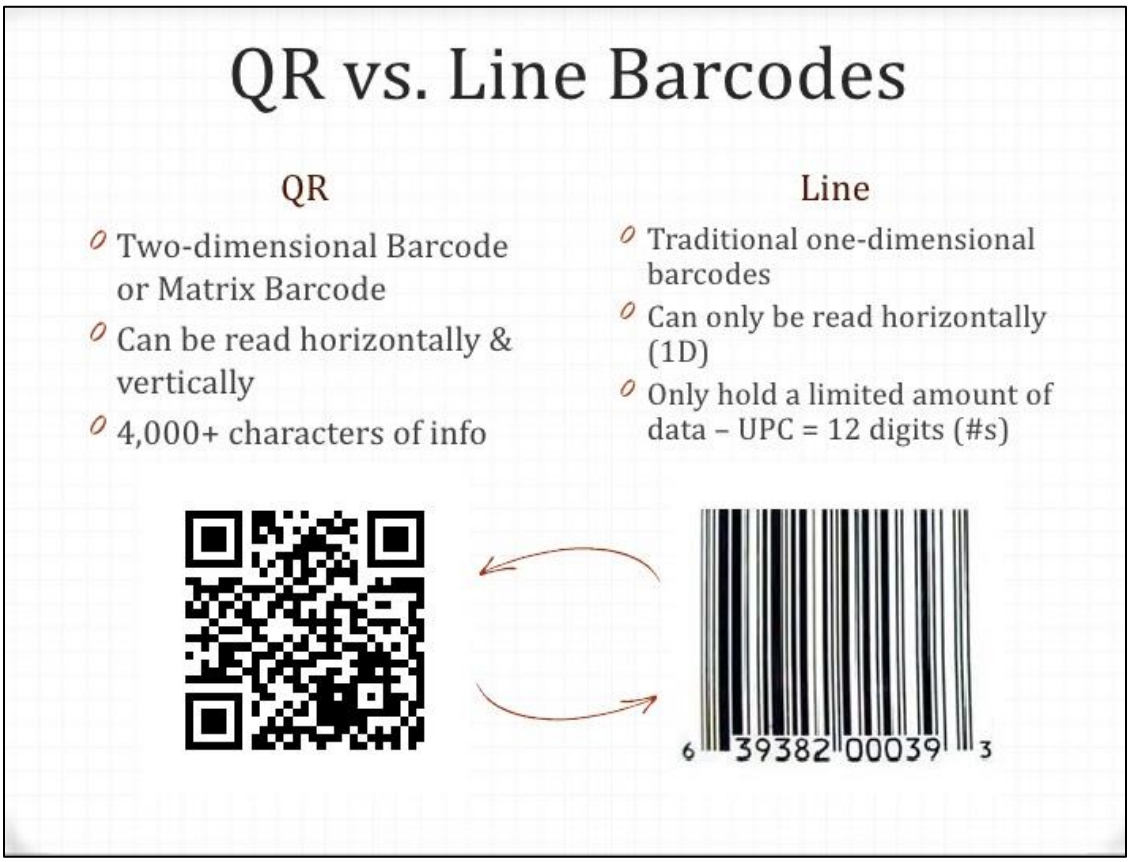


Figure 10. QR code versus Traditional Barcode shows the differences and similarities in technology. The QR code message is a URL for the Wikipedia page on QR codes and the barcode simply outputs the numbers "639382000393." Source: Cirino (2011).

The programing of QR codes follows the same fundamental principles of most data encoding. It can be done through many forms, to include binary coding where 0's and 1's combine to represent more complex characters like the alphanumeric system that are used to communicate through writing. Figure 11 represents the creation of a QR code from characters that can then be recreated so that the end user can comprehend the information. Figure 11 serves the purpose for the reader's conceptualization of an example how many characters can be represented by a small black and white square within a QR code. More information on the principles and technical details of QR codes can be found in Appendix B, the Wikipedia page for QR codes, as well as in Lucas's thesis, Digital semaphore: technical feasibility of QR code optical signaling for fleet communications.

Figure 11. High text capacity is shown as a QR code. The QR code outputs the alphanumeric characters to its left. Adapted from Performance image (n.d.).

3. Benefits

QR codes offer quite a few benefits combined into a small, simple and distinguishable package. The sheer amount of characters that can be packaged into the small square lends itself to applications for information communication. A message can be sent or displayed where any device with a QR scanner can make the code readable for a user. One major benefit of the QR code is that it does not require any network connection, only an application on the device itself. If a person using a smartphone is without Wi-Fi or cellular service, a QR code is still readable. Different capabilities beyond just text are able to be programmed into a QR code. ZXing's QR code generator has the capability to program a calendar event, contact information, email address, geo-

location coordinates, phone number, short message service (SMS) text, Uniform Resource Locator (URL), or even Wi-Fi network access information (QR Code Generator, n.d). Figure 12 and Figure 13 represent how a QR code can be created to scan important contact information into an iPhone. Imaging printing a QR code onto a business card, where a person no longer has to then manually input all the personal information into their contact list, but rather can scan the QR code and immediately have all the persons information stored. The ability to program a Wi-Fi network's information into a QR code is incredibly convenient as well. The ability to scan a QR code and have the service set identifier (SSID), password, network type, and whether the network is hidden or not makes advertising and joining an available secure Wi-Fi network very easy (QR Code Generator, n.d.). These features will be used in a later vignette for IO messaging of oppressed target audiences.

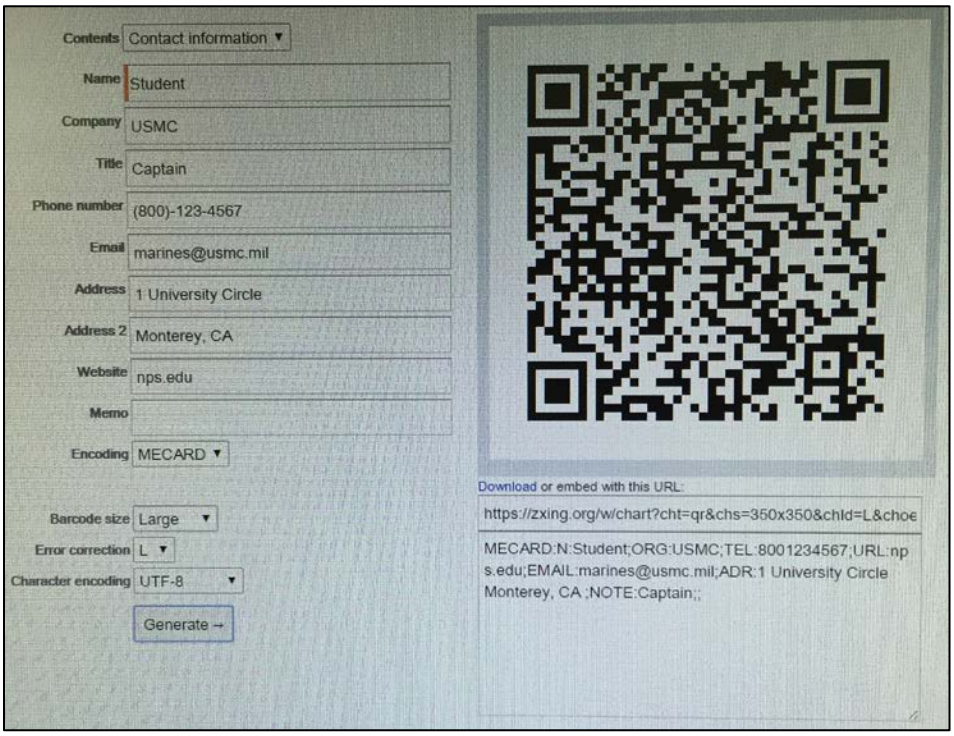


Figure 12. Contact information programing for the resulting QR code. The information input to the left side generates the QR code on the right side of the figure. The result of the scan of the QR code is shown in Figure 13. The QR code is scan-able and will result in what is shown in Figure 13.

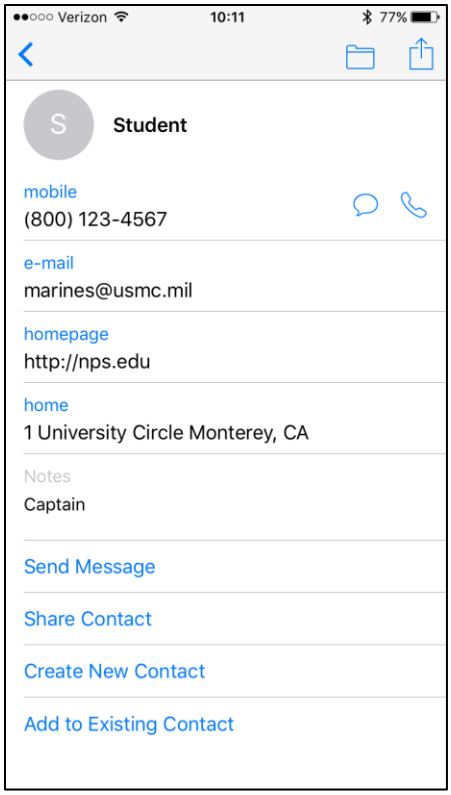


Figure 13. iPhone contact results from the Figure 12 QR scan.

Hidden bits within a QR code can be readable by specific scanning devices, while remaining unreadable by all other scanning technology. Essentially this means that a QR code can be programmed to make specific information available to all people scanning the code, but the remainder of the information is only accessible to a specific intended audience. Take for example, a checkpoint in a hostile environment that provides individualized daily passes with QR codes to be scanned by security personnel for regular commuters. This checkpoint is on a known route for enemy fighters who pose as civilian workers. Suspected or tracked enemy fighters can be identified by intelligence sources and can be issued a pass with a QR code that is identical to the regular daily commuters but with hidden bits identifying them as suspected enemy without the enemy's knowledge of the identifiers in the QR code. Each time the potential enemy fighter has their pass scanned, the hidden bits are visible to the security personnel, which allows the security personnel to pay special attention to the potential fighter for any further action to be taken.

Other advantages of QR codes come with the fact that they are not language dependent and can be translated into any language. With applications available on many phones, such a Google Translate, text is able to be translated quickly and accurately enough to get the desired message across. Such apps even have the ability to translate without data connectivity and can scan physical documents or signs and translate the image immediately on the screen. QR codes also offer the advantage of being covert, in the open. This is to say that the QR code can be projected or displayed by other means and is not detectable unless it is visually seen. The QR code can sit in one place for hours, days, or months without an adversary force ever seeing or recognizing the presence through technology, unlike RF communications that are highly subject to interception. There is potential for QR codes to be displayed in print form where ink that will fade to white over time, lending even more to the covert concept.

a. Identification Features

When network connectivity is available on devices scanning QR codes, a whole new realm of capabilities become available. Each scan of uniquely generated QR codes brings with it specific identifying features. Analyzing the information received back from each individual scan offers the ability to potentially identify and classify the individuals. Within military terminology, this means there is potential ability to identify friend, foe, or neutral (IFFN) target audiences.

Some of the features within the analytics capabilities are currently available through QR code creation websites. These analytic capabilities are all available by tracking scanning traffic using an associated URL. One example is QRstuff.com, which offers the ability for a subscribing user to track the date, time, location and device type for each scan. This is available only when using a shortened URL associated to each generated QR code. An example of the resulting product given to the user is shown in Figure 14. Many other websites and services exist for website analytics. Google has a whole division associated with website analytics. Google Analytics offers many different options for tracking traffic. They advertise that they allow you the ability to "get to know your audience" (Google Analytics, n.d.). "Google Analytics helps you analyze visitor traffic and paint a complete picture of your audience and their needs. Track the routes

people take to reach you and the devices they use to get there" (Google Analytics, n.d.). Google's analytic and tracking capabilities have revolutionized marketing and advertising, and will be addressed in the next chapter. It is important to again note that these analytic services are not offered directly from the QR code, but each QR code has the ability uniquely with a shortened URL. Also, these capabilities rely upon data connectivity and traffic.

The capability to track individuals accessing a QR code offers a direct feedback to the creators of the QR code. Each QR code is created with a specific application in mind, whether that is to advertise, inform, or cause malicious effects. Using analytics on the registered scans of the QR codes provides beneficial information to the creators and allows for adjustment to achieve more valuable desired effects. If QR codes are added to military IO messaging products given to different target audiences, these features will provide IO practitioners an enhanced ability to identify if the message is reaching the correct target audience; where, when, and how frequently. This enhanced ability to gain this sort of feedback can result in an enhanced measure of performance (MOP).

Additionally, the analysis of anonymous data provided by each scan can be used for a more detailed and individualized analysis. In a New York Times post, "With a Few Bits of Data, Researchers Identify 'Anonymous' People," researchers were able to analyze basic records of credit card purchases that had all personally identifiable information, to include account numbers, removed to identify and associate each purchase to each individual with 90% accuracy. Given further research and pattern identification, the researchers were able to use publicly available information, like Instagram or Twitter posts, and re-identify the credit card records to specific individuals by name (Singer, 2016). Multiple studies are cited in the post, to include re-identifying "Netflix users in a database of nameless customer records" and "patients by name in a supposedly anonymized hospitalization data set made publicly available by Washington State" (Singer, 2016). If such inference can occur with anonymous data sets, it is no doubt a capability that is available to the military in order to go beyond IFFN to identify individuals within the target audience of IO messaging campaigns that utilize the capabilities offered by QR codes and the analytics thereof. This topic is examined in the next chapter in much greater detail.

Figure 14. Example representation of a QR code scanning analytics that shows the number of scans over a period of time and the location of those scans by country. This is only a representation and can be conducted in further detail with proper authorization. Device types and operations systems are able to be determined as well, which leads to even further potential for identification purposes. Source: Analytics screenshot (n.d.).

b. Malicious QR codes

Since a person has no way of authenticating who or where a QR code was generated, malicious QR codes have a potential application with offensive tactical employment (Chilik, 2011). Just like malicious code that individuals must be aware of, Standard Query Language (SQL)-query injection and command injections are two techniques that can be used to run commands on the system reading the QR code. Also, fraudulent advertising QR codes that automatically charge outrageous fees can be used and distributed to a target audience in order to have effects on the economic standing of that country. Such false advertisements have been used by bad actors in countries such as Russia in the past (Kieseberg et al., 2010, 434). However, if the United States were to utilized such attacks, it should only be implemented during a congressionally declared war with some modifications to restrict the target population and secondary effects. Using JavaScript QR code or other injection attacks, friendly forces could display a QR image with knowledge that an enemy satellite is overhead, ready to scan the code (Chilik, 2011). If the attack is successful, friendly forces have the potential to gain access to enemy networks or systems. While much of these techniques might be considered under the realm of offensive cyber operations (OCO), these are possible techniques that could be pushed down to a lower approval level than the national level, even potentially to theater commanders or the first flag officer in the chain of command.

The concept for malicious QR codes allows for unique uses by OCO. QR codes offer linked information that is passively "hiding in plain sight." This is to say that the QR code is just sitting there where an opponent could see the QR code and scan it in order to gain access to what they perceive to be as sensitive information. In fact, the QR code is set up to reverse the roles as soon as it is scanned, allowing for friendly forces to act as the aggressor and gain access to the opponent's system. Essentially, QR codes off the ability to mix up the roles of who is an aggressor and who is a defender, sometimes in several ways at once.

4. Limitations

Security of QR codes needs to be addressed in three separate but related topics when used for tactical optical communications of friendly forces; interception, image manipulation, and malicious codes. Just as it is a benefit for friendly capabilities, QR codes can be used for malicious programming, execution of other codes, spyware, or other social engineering and phishing attacks. These attacks can occur when a friendly satellite or UAV roams over an enemy injected QR code and processes the code. There are many security measures already in place in information systems, but SQL-query injections and command injections may still occur (Kieseberg et al., 2010, 434).

Interception will always be a possibility for any form of visual signaling, however with optical communications there are risk-mitigation measures that can be implemented. First and foremost, the data that is used to create the QR code image can be encrypted prior to coding. This technique can easily be achieved with the encryption key's integration into the programming used on both ends of the line of communication. This solves any potential issue of key mismatching or lack of encryption coordination. Utilizing encryption techniques will allow the enemy to see code, but have no access to the data without the encryption key. A second countermeasure to interception is to use what QRcode.com refers to as secure quick response code (SQRC). SQRC essentially is an encryption but at the receiving side of the line of communication specific equipment is required. This form of QR coding does not look any different nor does it have any negative changes to the coding and reading process. In fact, when SQRC is used, it is possible to present data that can be read by someone with an open-source QR readers and also include data only accessible by SQRC specific applications (QRcode.com). This might have excellent benefits in physical security or deception operations. Once again, it is relevant that encryption and authentication techniques can already be applied today to the data and links contained within QR codes.

Image manipulation can easily be accomplished since the squares making up the QR code are black and white. An adversary with physical access to the QR code can easily manipulate the image and alter or destroy the information that is encoded in that image. This is less of an issue if the code were being generated on the spot by a

ground unit that was making the image available for satellites or UAVs passing over. However, if QR codes are used for any sort of information operations campaign at the tactical level, image manipulation can potentially cause second and third order affects that are not planned for.

Kieseberg et al. outline three separate measures that can be taken to prevent alteration in the data output when coupled with error correction properties of QR codes. The first is the mask that makes QR codes that achieve close to a 50:50 ratio of black to white area. Masking is encoded separately from the error correction and data coding, which allows it to use its own stronger error correction algorithm (Kieseberg et al., 2010). Mixing different modes help to prevent manipulation. Modes are the form of characters used to encode the message; i.e., numeric, alphanumeric, 8-bit, and Kanji characteristics (Kieseberg et al., 2010). A key feature of the QR code is the character count indicator, which tells the reading QR application how many characters it should be expecting in order to help with error correction. If this specific cell is not altered, then an observant receiver can tell if a QR code has been altered or not. If it has been alerted, the user can also tell if a buffer overflow has occurred (Kieseberg et al., 2010). A combination of all three measures makes for the best error correction programing.

Additionally, the security of QR codes can be addressed through all aspects of the confidentiality, integrity, and accessibility (CIA) triad for information security. All three aspects of the CIA triad have already been addressed above, but within confidentiality also falls the ability to authenticate with a password, to assure the person accessing the information is authorized to gain access. QR codes not only offer the capability to program encrypted information, but they can also require a password in order to make the information within the QR image readable after scanning by the users device. This will ensure that the information is not read by persons who are not intended to read the openly displayed QR code. Passwords are associated to individually created QR codes, so replication of the same code will require the same password (QRstuff.com, n.d.).

5. Forward Error Correction (FEC)

Forward error correction (FEC) is the ability for the QR code to detect that there is an error within the pixels of the QR code and to then correct the error. This is similar to how error detection and correction occurs within the transfer of packets over the Internet through their checksums. The checksum is a value that is sent with the packets, and its recomputed by the receiving end and then compared to the checksum that was originally sent. This is the basic principle that is used for QR code error correction skims, in particular Reed-Solomon error correction (Reed-Solomon codes for coders, 2016).

FEC within QR codes is dependent upon the different zone within the image. These zones are identifiable to the QR reader by the three very distinguishable and large squares in the corners of the image. Each zone represents different information through the black and white squares in the form of 0's and 1's that allow for the detection of errors. The zones represent message data, the format of error correction, error correction bytes, and format information. This is depicted in Figure 15. Once the error is detected, the error can be corrected by using the minimum Hamming distance (Reed-Solomon codes for coders, 2016).

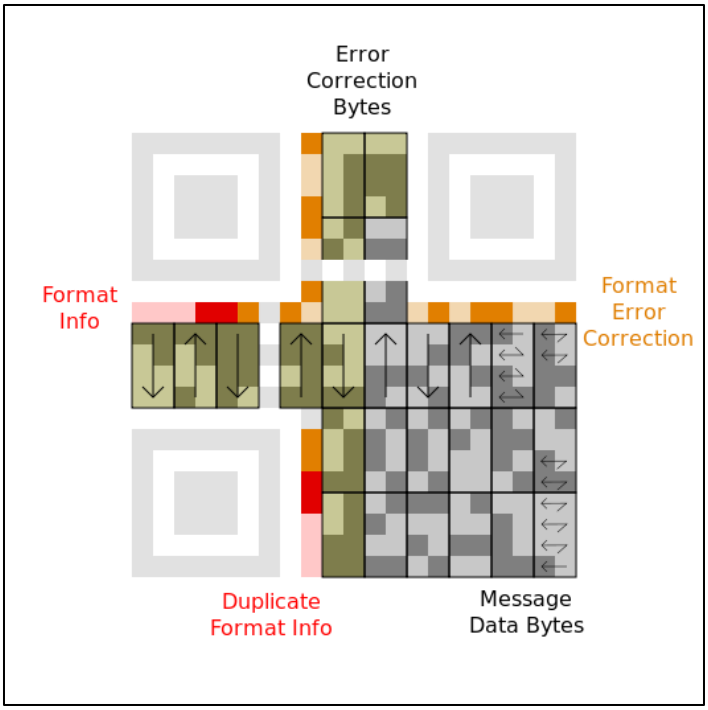


Figure 15. Forward Error Correction (FEC) adds reliability despite partial loss of data in QR codes. “Data bits are read starting from the lower-right corner and moving up the two right-hand columns in a zig-zag pattern. The first three bytes are 01000000 11010010 01110101. The next two columns are read in a downward direction, so the next byte is 01000111. Upon reaching the bottom, the two columns after that are read upward. Proceed in this up-and-down fashion all the way to the left side of the symbol (skipping over the timing pattern where necessary). Here is the complete message in hexadecimal notation. Message data bytes: 40 d2 75 47 76 17 32 06 27 26 96 c6 c6 96 70 ec Error correction bytes: bc 2a 90 13 6b af ef fd 4b e0” (Reed-Solomon codes for coders, 2016). Source: Reed-Solomon codes for coders (2016).

There are built-in four levels of FEC defined in the QR code standard: low (L), medium (M), high (Q), and ultra high (H). With the increase from each level of FEC comes the increase in complexity of the QR code, meaning that the QR code becomes more detailed with more pixels. The complexity of the QR code enables a higher percentage of the QR code to be obstructed or distorted as is depicted in Figure 16.

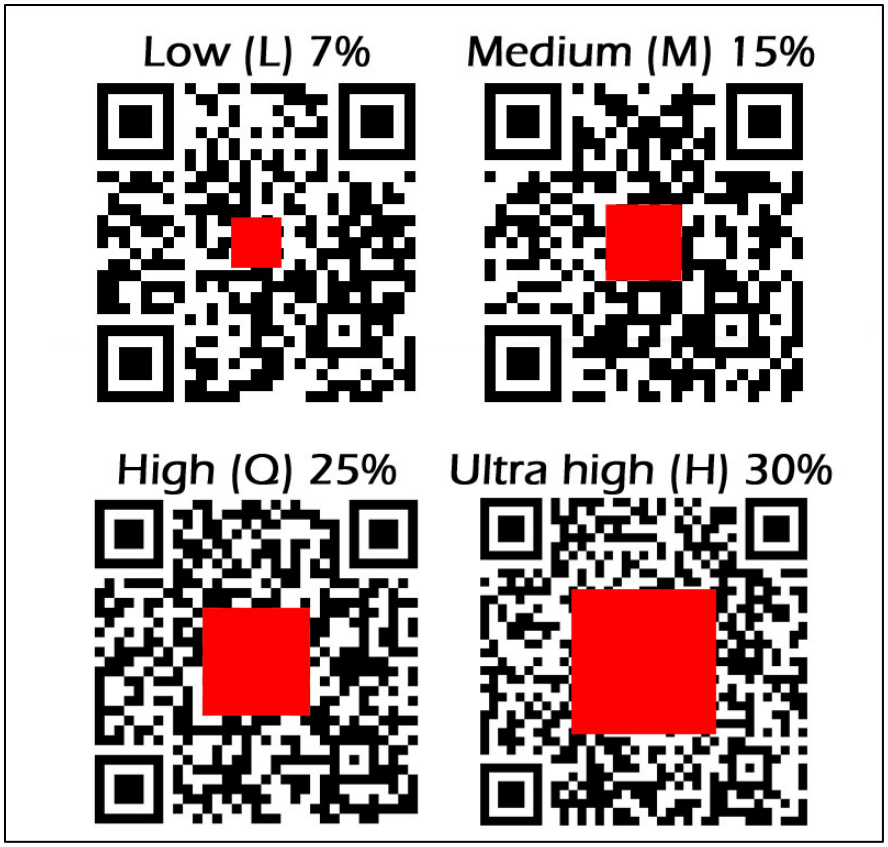


Figure 16. Levels of Forward Error Correction (FEC) and the percentages of the QR code obscured. The QR codes all scan to say "iQR Codes – custom QR code generator." Source: Tutorial (2012).

The ability to overlay an image on a QR code is critical for the application of QR codes within IO. Overlaying an image on top of the QR code gives the target audience an idea of what purpose the QR code serves, or even who the QR code is associated with. An example of this is in Figure 17, where the North Atlantic Treaty Organization (NATO) emblem is overlaid on the QR code where the information for the target audience is stored. It also is a practical example of how FEC can actually work when applied to a real product. Overlaying an image such as the NATO emblem or the Marine Corps Eagle, Globe, and Anchor will positively correlate for many people resulting in a feeling of comfort when scanning the QR code associated product.

Figure 17. Forward Error Correction: Functioning QR code with Image overlay. The QR codes to the right and the left of the NATO messages are modifications of the message programmed into a QR code. After the code was created with FEC, an image of the NATO emblem was overlaid onto the QR code. Even after approximately 20% of the QR code was obscured, it is still able to be scanned and the message will display. This is a different QR code than in Figure 21. Adapted from Friedman (n.d.).

D. AMPHIBIOUS OPERATION VIGNETTE

In order to understand the operational benefits of the optical communications technology discussed in this chapter, a short vignette focused on the bidirectional optical communications capabilities is provided in which the optical communications technology is applied to an amphibious operations scenario. This vignette serves the purpose of focusing on the bidirectional flow of information provided by optical communications. With half of the world's population living with 60 kilometers of the coast and 60% of all large cities located along coastlines, it is relevant to say that amphibious operations provide a relevant platform for the vignette (Cities and coastal areas, n.d.). The scenario

is depicted with the OV-1 diagram in Figure 18. DISCLAIMER: This scenario is purely notional and does not directly represent any country or adversary currently facing the United States.

The USMC's 15th Marine Expeditionary Unit (MEU) waits aboard U.S. Navy ships just over the horizon from the coast of the country Red. Country Red has been in violation of multiple United Nation (UN) sanctions because of their continued nuclear program development. The "red line" has been crossed for country Red and the President of the United States has ordered the Marine Corps to conduct an amphibious operation in order to deter further violations, or ultimately to seize control of the nuclear facilities. The most concerning issue facing the Marine Corps' team of planners is the EW capabilities of country Red. Country Red possess incredibly advanced RF communications intercept and jamming technology which pose a concerning threat to the 15th MEU's ability to maintain C2 of its forces in transit from ship-to-shore and once landfall has been achieved.

Luckily for Marine Corps planners, the 15th MEU spent a significant portion of their workup period implementing new technology to avoid dependence on the current RF communications capabilities. They became proficient in using optical communications technology such as DFL, VLC, and even developed tactics, techniques, and procedures (TTP) for using QR codes to communicate from forward forces back to higher headquarters aboard the ships. Since the 15th MEU has accomplished such proficiency and employment of optical communications TTPs, they are able to steam just over the horizon, splash amphibious assault vehicles (AAV), Higgins boats (LCVP), and Landing Craft Air Cushion (LCAC) vehicles and begin their movement to shore without a single RF communications signal being detected by country Red's EW forces. Thus, the landing forces is able to maintain the a partial element of surprise, even while conducting minimum essential mission communications optically.

Once the initial landing waves makes it to Landing Beach 1 and Landing Beach 2, they are able to signal back via the DFL that became part of their Battalion Landing Team's (BLT) organic communications equipment. Wave two is then sent, as wave one maintains the initial foothold on the beachheads. Optical communications relay stations

are enabled as a built-in part of the signal lights used to identify amphibious landing lanes. These optical communications relays are monitored by forces afloat using stabilized high-resolution optics with onboard video-distribution systems. Meanwhile fighting intensifies and the BLT is able to send back contact reports and situation reports as well as casualty evacuation requests. Logistical resupply request are also sent over the optical communications channels. Country Red's EW forces are increasingly frustrated because they are unable to detect, much less, disrupt the landing forces ability to communicate and to conduct their C2.

Fighting continues but ultimately reconnaissance forces have been able to make their way forward past the defensive posture of country Red because of the successful amphibious landing. They are now at the nuclear facilities and are undetected, but maintaining communication with higher command and awaiting orders. This is made possible by the digital QR LED mat they are able to unroll, lay flat and program multiple messages onto. Meanwhile the Combatant Commander's UAV assets fly over and regularly scan the QR code and transmit the image back to the ships via VLC. These capabilities allow for the reconnaissance units and the high-flying UAV to maintain their stealth nature. The order comes to seize the nuclear facilities. The operation is a success. Following mission analysis and the after action report is released, much praise is given to the optical communications capabilities. Ultimately, these new capabilities are credited with providing the agility, stealth and surprise needed to accomplish the mission. Without such capabilities, the mission might have come to a dead halt before it even began due to country Red's advanced EW capabilities.

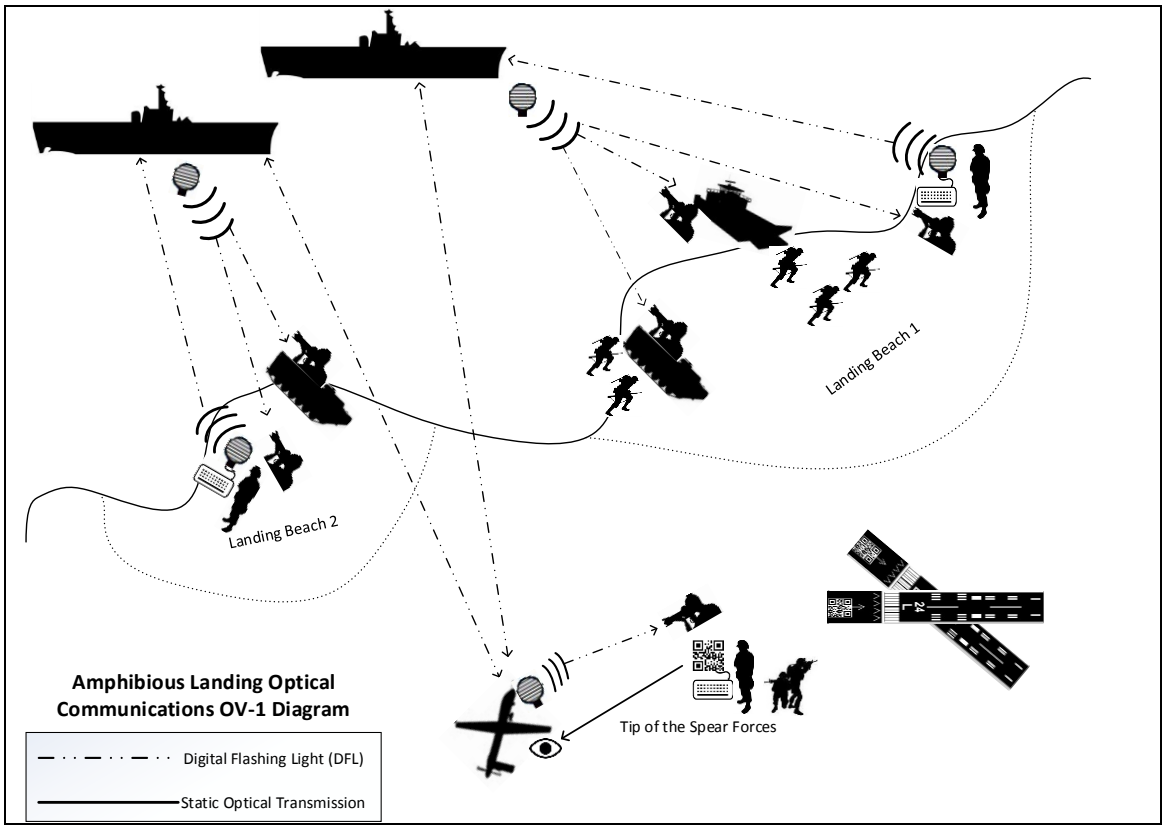


Figure 18. Amphibious Landing with Optical Communications OV-1 Diagram offers a concept of operation for an amphibious operation during the ship-to-shore phase and follow-on phases, using only optical communications channel and circumventing the RF spectrum. The diagram represents optical communications through DFL and QR code scans; however, VLC and future concepts of Li-Fi could easily replace the DFL, leading to greater data streaming rates.

E. SUMMARY

The concept of a bidirectional optical communication systems leads to another optical communication tool, QR codes. QR codes offer different advantages such as available infrastructure, forward-error correction (FEC) robustness, and right-time right-place asynchronous time latency. Together these features can provide a new approach to messaging within IO. Due to the major benefits of QR codes and the capabilities that the technology offers, QR codes can create a unique approach to how messaging within IO can be conducted. This concept of the bidirectional information flow can be further understood with a study of marketing and advertising techniques. Once these benefits are

understood, they can then be coupled with QR codes, and the result will be a beneficial tool for gaining feedback from target audiences in IO messaging.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. REVOLUTION IN MARKETING THROUGH BIDIRECTIONAL COMMUNICATION

A. OVERVIEW

Information Operations (IO) are a coordinated effort between many different military Information-Related Capabilities (IRC) to influence, by information, a target audience. Merriam-Webster' Dictionary defines marketing as; "the process or technique of promoting, selling, and distributing a product or service" or "the activities that are involved in making people aware of a company's product, making sure that the products are available to be bought, etc." (Marketing, n.d.). The similarities between an IO campaign and that of a marketing campaign are eerily similar; both seek to control and present information to an audience to elicit a specific behavior. The product that both IO and marketing want to deliver to a group of people may be completely different in desired effect and intent however they both must message (or advertise for marketing) these audiences and attempt to influence the audience to gain the desired effect, or push the product for purchase. One important distinction needs to be made; marketing does not involve the life or death of audiences as a direct result of its messaging. The dealings of life and death or imposing ones will on another means that the target audience's cognitive process involves a much stronger will to reject information in order to survive. Therefore, application of traditionally marketing techniques to IO campaigns does not necessarily guarantee success, but techniques from direct marketing do offer distinct benefits for evaluation.

Strategic communications can be seen as a small marketing campaign since its goal is to coordinated programs, plans, themes, messages, and products synchronized with the actions of all instruments of national power, as per Appendix A. A major portion of the marketing campaign comes in the form of advertising. The correlating principles of advertising in marketing to IO would be through non-kinetic messaging via products, such as leaflets, and news stories via public affairs (PA) or Key Leader Engagements (KLEs). Many more similarities can be drawn between the two, however these are the largest.

While both IO and marketing might well seem similar, marketing is far more practiced in its ability to develop campaigns, reach the audience, and measure how well their campaign is doing. Ever since the majority of sales shifted from storefront to Internet-based sales, marketing has revolutionized the way it brands products and advertises to specific audiences. Technology resulting from the Internet-boom has created unique platforms that allow more direct marketing and targeted advertising. There are many aspects within current marketing strategies that could be learned from and used to further develop the TTPs within non-kinetic targeting IO campaigns when paired with new technologies such as those discussed in this work.

B. SUPER BOWL ADVERTISING

The best way to understand the evolution of marketing (and ultimately advertising) is to look at advertising as it relates to the Super Bowl. Many people will agree that of the over 100 million viewers that tune into the Super Bowl, a vast percentage are not watching for the down and distance, but rather the commercials between the downs (Villapaz, 2014). Such viewership fascination with the commercials was not always the case, and there is an argument that it currently is no longer true. The evolution of how the Super Bowl advertising has changed gives "fascinating evidence of the powerful and unprecedented speed of transformation in the world of marketing" (Dholakia, 2016).

One of the first Super Bowl advertisements commonly considered to be iconic was in 1979 when the Pittsburgh Steeler's "Mean" Joe Green starred in the iconic Coca Cola ad, "Hey Kid, Catch!" In this advertisement "Mean" Joe Green was walking back to the locker room injured and defeated when a little child offered him a Coke, and in returned Mean Joe tossed back his jersey (Villapaz, 2014). This ad was repeated during the 1980 Super Bowl as well, and throughout other parts of the year, but no ad had made such a large iconic impact prior to that. Fast-forward a few years to 1984 and Super Bowl XVIII, the teams are not important, only the 60 second commercial that introduced the Macintosh personal computer by Apple to the world (Conway, 2014). Advertisements

during the 1970s, 1980s and the early 1990s can be summarized by longer narrative advertisements.

1995 and Super Bowl XXIX left everyone talking about three frogs who croaked "bud" "weis" and "er" for thirty seconds. Five short years later, everyone was screaming "WASSSSUP" the next morning at work, thanks again to Anheuser-Busch (Villapaz, 2014). E-trade even made a splash in 2000 with two 30-second commercials, "Out the Wazoo" where a man is rushed to the emergency room and all the doctors can determine to be wrong with him is that he has more money than he knows what to do with. The second commercial is considered an all-time classic and it perfectly describes what was currently happening to Super Bowl advertising. A chimpanzee presses play on a tape deck, and then stands on a bucket dancing between two adult men sitting on lawn chairs inside their garage while "La Cucaracha" plays. Finally, after twenty seconds of the commercial, the screen go black and displays, "Well, we just wasted 2 million bucks. What are you doing with your money?" Later, E-Trade saw even greater success with the set of commercials with the talking baby. This began the era of the short, attention-grabbing commercials that cost ridiculous amounts of money. Since then, "entire websites and media outlets have been created for no other reason than to feature, analyze and archive Super Bowl commercials" (Conway, 2014).

Since the year 2000 until the last few years, one of the largest design changes has been the connection to digital media outlets and social media. For example, in 2013 there was an estimated 100 million viewers for the Super Bowl, but there were 265 million views for the 2013 Super Bowl commercials on YouTube, with a third of those views coming before the game even started (Conway, 2014). With social media, the number of social media shares has become a new measure of the success of the advertisement. On the day after the Super Bowl in 2013, the total number of shares on all social media platforms for all advertisements that aired the night before was 3.3 million (Conway, 2014).

"The fact that Super Bowl ads are awaited with such interest ironically highlights the fact that traditional television advertising is dying" and need further explanation as to why they are still relevant (Dholakia, 2016). Now, super bowl advertising is not

advertising but a representation of status within pop culture. But even so, the ads are on the verge of "drowning themselves out" (Dholakia, 2016). Frito-Lay has been implementing a brilliant strategy for their Super Bowl advertisement, in order to make the return on investment necessary to offset the outrageous cost of advertising. Their Chief Marketing Officer described the idea of letting consumers create their own Super Bowl ads and then vote on them as "not a one-and-done deal on the game day. It's basically this five-to six-month engagement program that we had with the consumer" (Dholakia, 2016). Currently most Super Bowl advertisements come with a "digital call-to-action" which means they push a product as well as a website to visit, a hashtag to tag social media posts with, a Twitter handle to follow, or a promotional code to use; all this in order to enable the marketing teams to measure the effectiveness of the advertisements (Dholakia, 2016). The utilization of these "digital call-to-action" metrics allow for far more advanced analytics than ever before.

According to Dholakia (2016), not all ads are getting through in the over 3000 average daily exposures bombarding consumers. This is mostly due to the relevance and quality of the advertisements being presented to the consumer. Even with on-demand shows and movies, and the advent of digital video recorders (DVRs), most commercials are not even watched anymore, with the exception of Super Bowl ads as previously shown. Why is this? It is due to the competitive creativity and storytelling that is within Super Bowl ads. Resources and money are placed into the creation of these ads, and the results justify the expenses. Dholakia says that all marketing tactics "will continue to be just noise until they are both entertaining and relevant to the consumer." This quote can be directly transferred to IO practitioners, if marketing is replaced with messaging and consumers replaced to target audiences. Such connections next lead to the nature of communicated information and the establishment of relationships.

C. DIRECT MARKTING

One definition of direct marketing is "a database-driven interactive process of directly communicating with targeted customers or prospects using any medium to obtain a measurable response or transaction via one or multiple channels" (Flee, n.d.). The key

areas of this definition are the focus on the interactive nature with direct communication, to a specific group, resulting in a measureable response. In order to obtain a measurable response, a bidirectional system must be used. This does not mean that the targeted customer is writing an email or filling out a survey to communicate directly back, but that the actions taken by the targeted customer are measurable and communicated back to the marketers.

There are, however, forms of direct marketing that do rely upon the direct interactive nature of its advertising (Flee, n.d.). Originally, marketing relied upon door-to-door salesmen, and then shifted to direct marketing with databases and catalogs for stores such as Sears. After these changes came catalogs through which purchases could be made directly from them by calling the company, like Lands' End or L.L. Bean. This form of sales lent itself to greater abilities to measure responses. The ability to measure responses was improved with the prominence of credit card sales. After credit cards, the personal computer coupled with negative attributes of the in-store shopping experience lead to the advancement of Internet sales. Internet connectivity and web content created a medium that seemed endless in its ability to push out branding information and measure or generate a response. These evolutions lead to a greater relevance for the direct marketing industry (Flee, n.d.).

1. Google AdWords

One major change within direct advertising is an ability to gain greater and more measurable online advertising through a unique avenue. Google was not always as well-known as it is now. During the early 2000's the Internet began to boom and dot.com businesses started to bloom (apparently from nowhere) and suddenly disappear just as fast. Search engines began to evolve, some better and faster than others. GoTo.com, which later turned into Overture, was the first real revolution in the search industry, but Google seemed to be the company with all the luck (Battelle, 2005).

Early search engines using simple algorithms for key terms began to become spam engines. websites that had nothing to do with the term being searched, would pepper their site with these key terms and would thus become top hits for the searcher.

An example would be searching the word “car” and having the top results come back that were adult-entertainment industry websites (Battelle, 2005). Bill Gross, a wildly successful entrepreneur, theorized that “to kill spam, one must add the friction of money to the (search) equation” (Battelle, 2005, pg. 106). From this came two concepts; “a performance-based model in which advertisers paid for a visitor only when a visitor clicked through an ad and onto the advertiser’s sites” or “one cent per click, an extraordinary discount” when traffic was being bought for much more (Battelle, 2005, pg. 109). The second of the two strategies led Google to be able to implement the first strategy via intentional traffic. This is because the quantity of traffic was less profitable for sales, but the quality of the traffic is what led to quantifiable sales results. This lead to the company, Overture, and ultimately is how Google became the giant it is today; pay-per-click advertising (Battelle, 2005).

The early success of Google over all other search engines earlier on was a combination of three factors, of which Google had all; high-quality organic search results, paid search network, and ownership of its own traffic (Battelle, 2005, p. 117). Google is a stand-alone website with a strong search algorithm. It also has its paid search network which was a direct spin off of what Bill Gross developed early on even though Google originally found this concept detestable; AdWords (Battelle, 2005). AdWords has developed into Google’s premiere advertising service, which associates words to paying advertisers. Ads are placed into webpages that are related to the content of the webpage or previously visited pages. Higher paying companies have their pages placed at the top of google searches, and there is even a section placed at the top of search results that are shown as paid advertisements. It targets ads for specific individuals through collected data.

As time has progressed, several major near-monopolies have emerged (Google, Amazon, Facebook, Apple, LinkedIn, and others) based on their ability to correlate, track and analyze current and potential customers. Indeed such databases and algorithms are considered major business assets in their own right. Attention must be paid to individual-focused feedback loops to remain effective.

2. Data Collection

Google's dominance within the search realm led to further developments for advertisers and marketers. Google's ability to target ads specific to individuals continues to increase through their ability to track traffic and collect data on individual Internet protocol (IP) and media access control (MAC) addresses. Some concern arouse over the Google's "reading your email" (Battelle, 2005, pg. 195). The fact was that they were not actually reading peoples' emails, but just scanning through text for words and phrases that matched up with those from the AdWords network. According to Daniel Brandt of GoogleWatch.org, the major concern that arises from this is that "now that Google (has) your email address, it could potentially tie your IP address to your identity," which then allows companies like Google to track your personal Internet usage (Battelle, 2005, p. 195). Indeed the Chief Executive officer of Sun Microsystems, Scott McNealy was quoted publicly to say "You have zero privacy anyway. Get over it" (Manes, 2000).

For a company like Google, which is ever expanding, the ability to track data and results to tailor advertisements becomes even more complex when Internet browsers developed by the company are introduced and coupled with Internet traffic cookies that are placed onto the browser for each website visited. When a person uses Google to search for a specific topic, they are presented with potentially millions of links to relevant websites. Google is able to collect massive amounts of direct and derivative data immediately when the person clicks on their preferred link on the results page. Before the person is directed to the website after being clicked, the Internet traffic is redirected to many different data collection sites that are associated with Google. An individualized and anonymous number is assigned to those specific devices that are being used to conduct the search and connect to the follow on websites. This all serves the purpose of providing better feedback to the customer as well as the business model of the pay-per-click advertising, because highly evolved feedback mechanisms function well even in the absence of Personally Identifiable Information (PII).

While these concerns arise, data collection is the best possible way to measure the effectiveness of advertising. As long as ethical guidelines are followed customer privacy can still be protected. The more data collected typically results in improved directed

advertising for each individual. It needs to be understood that Google is not the only company capable and currently using these techniques for advertising. Facebook also is able to tailor ads to individuals based upon web traffic and the specific page visits, event responses, as well as specific networks joined. The interconnected nature of all social networks is allowing for greater and more individually associated data collection as well. Given that such information is usually treated as trade secret, large companies tend to grow even larger due to steadily increasing competitive advantages.

3. Personalized Advertising

The ability to collect so much data on large numbers of individuals, especially with the application of anonymous yet-unique identifiers to that person, such as their MAC address being associated with registered email addresses or other accounts, allows for individually personalized advertising. One of the primary forms of this is retargeting or behavior retargeting. This is essentially taking the actions tracked online of individuals, analyzing those actions or behaviors and using algorithms to readjust the advertising for more relevant ads (Zhao, Yin, and Chen, 2011). The retargeting also takes into factor the ignored advertisements or links as well. Zhao, et al. found that the majority of behavior retargeting was focused on short-term user behaviors, rather than what might be thought to be more effective, longer-term user behaviors. This brings up an interesting point, that within a social environment many behaviors sway quickly based upon the influence of outside social connections. This concept is also pointed out in EBO theory.

Personalized advertising has a direct correlation to social influence sources because of the influence of the digital social networks that people are interacting on. Risselada, Verhoef, and Bijmolt (2014) studied the effects of combined social influences and direct marketing on whether or not groups adapted specific high-tech products. The researchers showed that both direct marketing and social influence had a positive and constant effect on new adopted technology, but that it died off over time. This is interesting when it comes to personalization of advertising and messaging because it shows that technologies and messages that are new have a bigger impact on the audiences rather than repeat technologies and messages.

D. PUSH VERSUS PULL

If one were to summarize the evolution in advertising it could be described by saying that earlier marketers relied on producer-pushed advertising, and now there is a consumer-pulled mechanism that allows for more effective advertising through relationships. Old catalogs, newspaper ads, television commercials, and mail advertisements all were pushed out to the masses. While some were semi-tailored to the audience of the current show on television or the section of the newspaper, most were blasted out to the masses with a hope it a small percentage might reach the correct target audience. They focused on pushing the information or product.

Currently with the data collection, direct marketing, behavior retargeting, and advanced analytics the concept for advertisement seems to focus on a pull from individuals in the correct target audience or customer group. The marketing firms and advertising outlets are pulling information about specific individuals and then are creating and pushing the more relevant ads to those individuals. Repeated pulls can lead to carefully designed interactions and trusted relationships.

E. SUMMARY

Looking at the revolution in advertising from Google's AdWords to that of how the Super Bowl advertising evolved allows for relevant lessons as to how advertising and marketing have become more effective. Marketing has shifted from focusing on long draw out campaigns and commercials to short, sweet and technology driven campaigns or commercials. The use of direct marketing allows and focuses on the results and the ability to measure these results. The technology and ability to track the results of each advertisement by individual through commonly used mediums allows for the greater ability to measure effectiveness of each ad. The similarities between IO and marketing have already been draw, now the relevant lessons learned by marketers must be applied by IO practitioners as well.

THIS PAGE INTENTIONALLY LEFT BLANK

V. ESTABLISHING FEEDBACK CHANNELS FOR INFORMATION OPERATIONS (IO)

A. OVERVIEW

As previously discussed, a goal of IO is to achieve influence over a target audience or system. The specific ways and means provided for by the IRC within the information environment are how influence is achieved over a target audience. The information environment consists of the physical dimension, information dimension, and the physical dimension, which are where the target audiences or systems reside and interact. Figure 19 depicts the information environment, the ways and means, and information flowing between all. Information flows between audiences or systems over the different dimensions listed above. The ways and means are the how practitioners achieve influence over the audiences and are also what must be measured for their effectiveness and performance. This chapter will discuss the deficiencies of current abilities to measure the effectiveness and performance of influence messaging directed at primarily human target audiences.

Current messaging is typically a one-way flow of information from friendly IO to the target audiences. The QR code offers an ability to provide feedback from the target audience to the IO practitioners via their interaction with the QR code by simply scanning the image. Another vignette is provided to show how this concept can be achieved through messaging of an oppressed populace. Examples of product concepts will also be presented. Finally, the idea of the Observe, Orient, Decide, Act (OODA) loop is applied to the IO process, for both the practitioners and the target audiences with QR code-based link' and messaging facilitating direct feedback. This chapter's purpose is ultimately to show that the concepts of the optical communications channel provided by QR codes, when combined with their technical capabilities for identifying individuals or larger audiences derived from direct marketing practices, can establish the feedback loops necessary for individual-directed communications, and then for more valuable measures of effectiveness and enhanced performance measures within IO messaging.

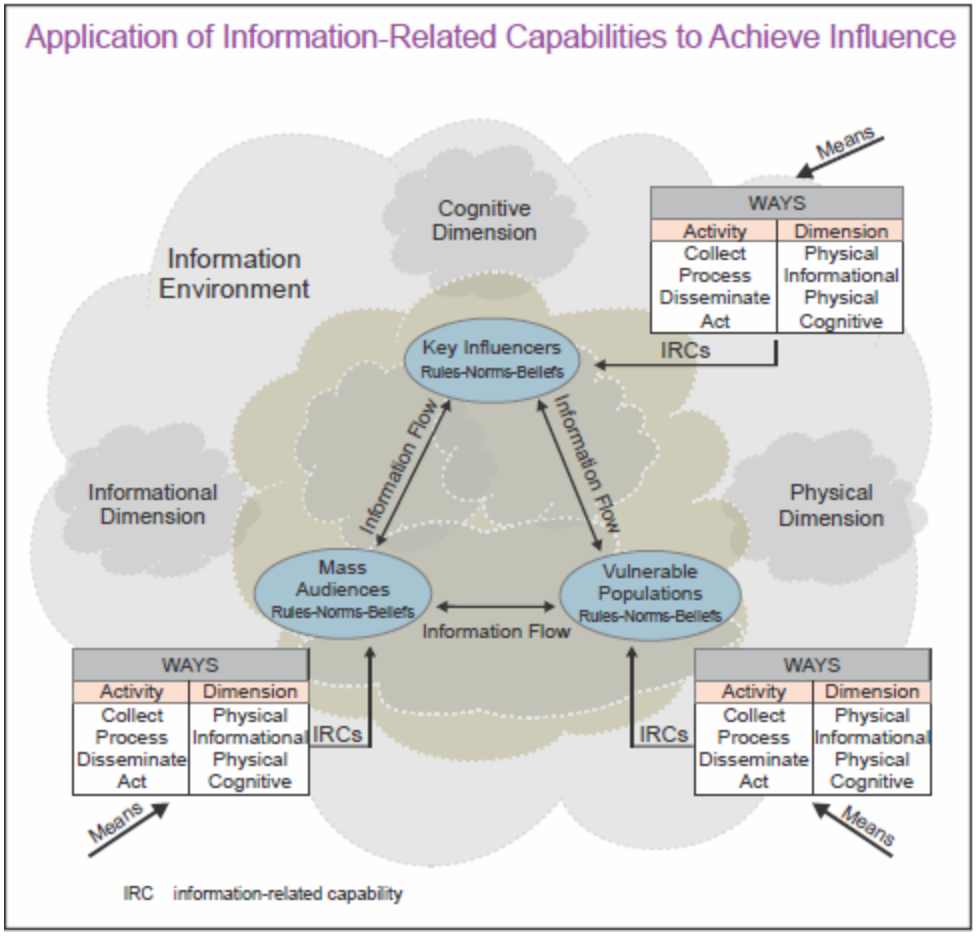


Figure 19. The application of Information-Related Capabilities (IRC) in order to achieve influence is complex. Source: U.S. Joint Chiefs of Staff (2012).

B. INFORMATION OPERATIONS (IO) SHORTFALLS

Joint Publication 3–13, Information Operations, acknowledges that assessment of IO effects is a difficult process. The techniques within doctrine that have been established to attempt to measure the effects are represented by measures of performance (MOPs) and measures of effectiveness (MOEs). MOP is defined by Marine Corps Warfighting Publication (MCWP) 3–40.4 as "a criterion used to assess friendly actions that is tied to measuring task accomplishment" (U.S. Marine Corps, 2013, p. 67). These are typically easier to measure because they quantify if a mission has been executed or not, by indicating how many products, messages, missions, etc., have been conducted or produced. These measures are intended to show whether the message is reaching the

audience, however just because x-amount of leaflets are dropped does not mean that the message is reaching the target audience. Simply put, the MOP tells whether or not the mission to create the IO effect was conducted.

Current concepts of MOPs are relatively easier to measure, while MOEs are much harder to measure. MCWP 3–40.4 defines MOE as "a criterion used to assess changes in system behavior, capability, or operational environment that is tied to measuring the attainment of an end state, achievement of an objective, or creation of an effect" (U.S. Marine Corps, 2010, p. 67). MOEs are designed to quantify intangible attributes within the information environment in order to afford the ability to determine whether or not the messages or actions being taken are achieving the desired effects (U.S. Joint Chiefs of Staff, 2012). Simply put, the MOE tells whether or not the effect is accomplished.

1. Measure of Effectiveness (MOE)

Joint Publication 3–13 acknowledges that there are shortfalls within the ability to measure IO effectiveness; "Effectiveness assessment is one of the greatest challenges facing a staff. Despite the continuing evolution of joint and Service doctrine and the refinement of supporting tactics, techniques, and procedures, assessing the effectiveness of IRC continues to be challenging" (U.S. Joint Chiefs of Staff, 2012, p. 47). These challenges are due to the attempt to quantify intangible attributes, which typically occur because of the desired influence effect lays within the cognitive domain. Measuring a person's reaction to a message or effect that is directed at changing a specific behavior through the person's thought process is nearly impossible unless he or she provides direct and explicit feedback indicating the change. Without the direct feedback from the target, the ability to measure effects requires the knowledge that a change has occurred. This means that a baseline must be established in order to measure any positive or negatively correlated change against. Combining all the complications of measuring the effectiveness of messaging during an information operations campaign makes for a challenging task.

2. Limitations of One-Way Messaging

Most of the limitations in current abilities to measure effectiveness and enhanced performance when related to messaging a target audience are induced by the one-way flow of information from IO practitioners to the target audience. The one-way flow of information means that generalized assumptions are required for the target audience regarding how they will perceive and react to the message. IO practitioners must assume generalized reactions when planning the messaging of target audiences throughout the whole of IO campaigns, because the end state is to achieve a desired effect on that target audience. The lack of ability to effectively and consistently gain feedback on the effects of messages throughout a campaign is what makes the assumptions so important. Measuring the atmospherics of the target audience when a message is delivered can be difficult, hence typically making the flow of information unidirectional. Intelligence capabilities and humans on the ground through IRC like CMO or interagency coordination are typically the best way to measure if the desired effects are being achieved. These means can, however, be risky and resource intensive. Nevertheless such feedback is typically naïve, culturally unaware and biased. If the one-way flow of information were able to be changed by gaining and measuring not only the delivery confirmation but the reaction of the target audience to a message disseminated over technology based channels, like those discussed earlier, then the ability to measure can be achieved and actual IO effectiveness and performance can greatly increase.

C. APPLICATION TO INFORMATION-RELATED CAPABILITIES

There are potential uses for QR code and optical communications employment during amphibious operations as well as for feedback in the IRC, specifically intelligence, MISO, deception, cyber operations, civil affairs, and public affairs. These IRC's are incredibly important during phases zero and one of military operations as well as throughout the whole range of military operations and phases of war. Public affairs can use QR codes to disseminate new articles or link to civilian media coverage with a smaller footprint. Civil affairs are able to use QR codes to create electronic handouts to inform the local populous of potential help and programs available that will turn the tides

of support to the US. Through deception, when units use digital semaphore, the SQRC is applicable and the data that is viewable without the encryption key can be used to convince the enemy of false plans. Friendly forces can confirm false assumptions the opponents and neutrals have against friendly forces and their strategy. Forces can allow "secrets" to slip accidentally, just as occurred during Operation Bodyguard during World War II. The use of QR codes in MISO messaging is just one more avenue of influence that is already available. Finally, the use of QR codes in human intelligence might open new techniques for forming the linkages between the enemy populace, and connect links that might never be otherwise discovered. By utilizing malicious QR coding, and disseminating this through advertising for relevant products to that country, intelligence communities can begin social engineering and network analysis of the country's communities from a new inside-the-loop perspective with the coordination from cyber operators.

D. TARGET AUDIENCE MESSAGING PRODUCTS

1. Oppressed Population Vignette

DISCLAIMER: This scenario is purely notional and does not directly represent any country or adversary currently facing the United States.

Country Red is modern technologically capable, yet still developing country located in an unstable region of the world with two ethnic groups that have a history of conflict and hatred. The majority ethnic group has recently grown and makes up 78% of the population but has been suppressed since the civil war 15 years ago. Dictator X is part of the minority ethnic group in Country Red, which holds all of the power and continues to oppress the majority ethnic group through physical coercion, torture, control of media flow, restriction of Internet traffic, controlling cellular networks, placing limitations on food and water, and strict enforcement of travel and curfews on the majority ethnic group. Within the international community, concern has risen over how the dictator of Country Red has been treating the majority ethnic group within the population, after an article that was published by a reporter who had spent months living disguised as a member of the majority ethnic group in Country Red gained viral status. Due to the news

throughout the world, the United Nations (UN) has decided to get involved. The first priority of the UN is to negotiate to allow humanitarian aid to the majority ethnic group. The UN has voted to intervene and take military action if all other attempts to bring change fail.

The United States has been given the lead on the humanitarian actions and also was given the warning order to make plans to take military action if significant change does not occur within six months. Information Operations are made an integral part within the planning process with an attempt to prepare the information environment during the humanitarian aid campaign for any military action to come later.

During the humanitarian campaign, the IO practitioners decide to implement the new techniques of utilizing QR codes for dissemination of information. QR codes are printed or attached on all humanitarian aid rations, water containers, and on to hygiene instruction pamphlets. Unique identifiers are contained within most coded URL links, allowing the location of each QR-linked web request to be correlated to specific locations and even message types (food, water, electricity, etc.) through web-based analytics of Internet routing and traffic flow. Mobile applications whose downloads are linked to QR codes and that utilize location services and geo-location are created, ranging from entertainment to news dissemination platforms for download by target audiences. UN workers lead instruction and demonstration on how to use QR codes and created applications resulting from the QR codes, which are given prior to all groups entering into the aid distribution centers. As with other humanitarian aid and disaster relief operations (HA/DR), ad hoc UN run cellular and Wi-Fi networks are set up all around the distribution camps to allow access to the Internet and the resources linked through the QR code in order to circumvent Dictator X's control of the cellular networks and Internet censorship. Thus, the populace is granted access to the open Internet, connecting them to the information distributed by friendly forces. QR codes are created that allow immediate access and connection of the scanning device to the local cellular and Wi-Fi networks. This also provides the UN forces the access to data traffic resulting in the ability to conduct analysis on the data traffic. The traffic analysis is conducted in order to identify who, where the physical products and applications are reaching, and establishing

baselines. Surges in populace interest on new or trending topics are also thus discernable. Since Country Red is only slightly underdeveloped, cellphone ownership has grown and become a staple of the population over the past 10 years, allowing for cities that are located outside previously laid wired telephone infrastructure to have access to telephone communication. This was common knowledge and thus planned for during the implementation of the QR concept of operations for the humanitarian aid.

Ultimately the UN was not satisfied with Dictator X's changes, as none truly occurred over the six month humanitarian aid campaign. Country Red's military forces began to posture as soon as the humanitarian aid operations began. US-led military action directed by the UN begins and the transition from humanitarian to military action focused IO messaging begins. Such messages are disseminated via the ad hoc networks established and mobile applications downloaded during the previous humanitarian aid period. Posters and leaflets are disseminated throughout Country Red's cities to the oppressed majority ethnic group. Safety and secrecy in receiving IO products is made possible for the oppressed majority because they do not have to physically carry anything other than the phone with them, no leaflet or pamphlet need to be carried by the concerned populace. Posters in town are quickly scanned and read later, as to not make the interested individuals a target for patrolling Red military forces. Based on interest and feedback, the majority ethnic group receives the messaging favorably and the MOEs and MOPs associated with the messages measure in a timely manner via the feedback received through the analytics made possible by QR codes and cyber capabilities.

IO practitioners also anticipate Country Red's military leaders and tactical level military forces also scanning QR codes intended for other target audiences. Honeypots and similar cyber-related capabilities are planned and executed through messaging and targeting of the military and country leaders. Through the scanning of these codes , perhaps triggered by contradictions in the location or responses, identification of key hostile leaders occurs and ultimately their locations are discovered. Tracking occurs via the geo-location capabilities built into the ad hoc network infrastructure and mobile applications geo-location services. The intelligence gathered by these technical means proves to be invaluable.

From these UN missions against Country Red ranging from the start of the humanitarian aid until the end of the military actions, the concept of operations proves true for the use of QR codes as a means to provide feedback and more efficient MOEs and enhanced MOPs for IO messaging campaigns. IO communities begin to explore more technically driven avenues for message dissemination enabling greater, quicker, and more accurate feedback from the messaging. Figure 20 shows a small and simple glimpse at the potential avenues to message an oppressed target audience when providing an ad hoc cellular network for connectivity.

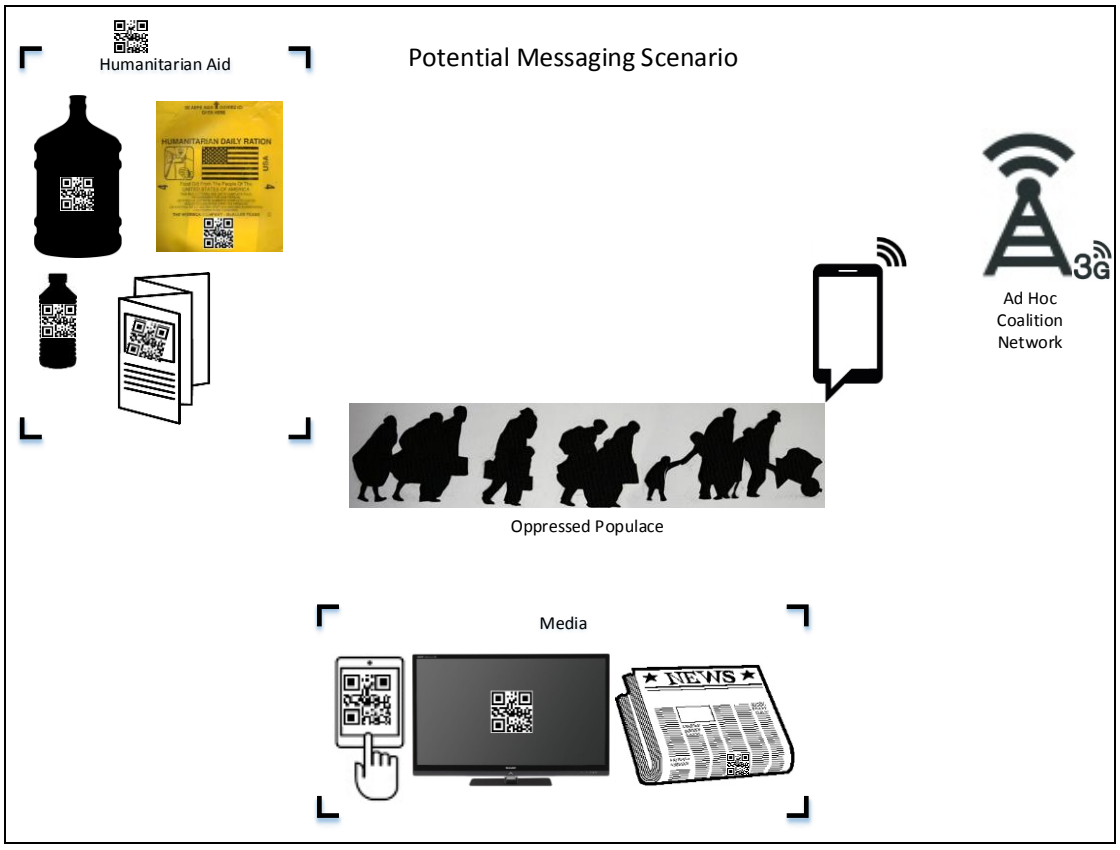


Figure 20. Oppressed population scenario shows the potential applications of products resulting from the oppressed population scenario in the vignette.

2. Leaflet to QR Code Example

Figure 21 is an example of a word-for-word translation from leaflet to QR code of an actual leaflet disseminated during the North Atlantic Treaty Organization (NATO) actions taken in during the 1998 Kosovo conflict. As is shown in Figure 21, the leaflet consists of two sides and uses two QR codes to present both portions of the leaflet. The top corresponds to the QR code to its right, and the bottom corresponds to the QR code to its left. The NATO emblem overlays onto the QR code after the QR's creation was complete; with the help of forward error correction, the QR code is still readable.

Figure 21. NATO leaflet converted to QR with NATO Emblem superimposed. Adapted from Friedman (n.d.).

Figure 22 shows the QR code scanning via the QR reader for iPhone application. Many different QR code scanning applications are freely available on Apple's application marketplace and on similar android-based application marketplaces. Some complications

do arise when scanning the top right QR code from Figure 21, as the coding is very dense, but not fully packed to programming capacity. The NATO emblem overlay combined with the density of the pixel imagery is what leads to complications. However, Figure 22 shows the top right QR code from Figure 21 after successfully scanning, which took two attempts. The results are clear and show the word for word message from the leaflet, combined with a URL link to NATO's official website. URL links that lead to data transmission over cellular and Wi-Fi networks allow for the data collection and analysis. Readers are encouraged to scan these QR codes (and all others appearing in the thesis) to confirm the effectiveness of these standards-based techniques.

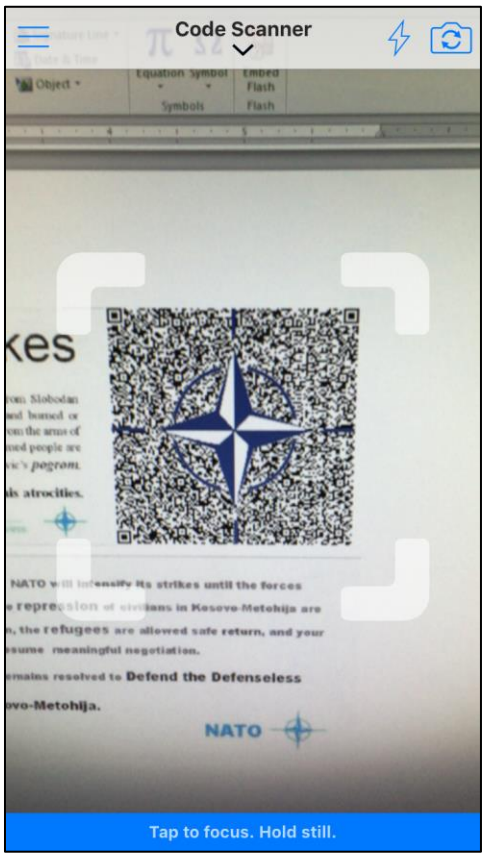


Figure 22. This shows the results of the front side of NATO QR code scanning. The top of Figure 21 was scanned using the QR Reader for iPhone, as proof that the image with the NATO emblem embedded into the middle of an already created and very congested QR code is possible due to the use of FEC

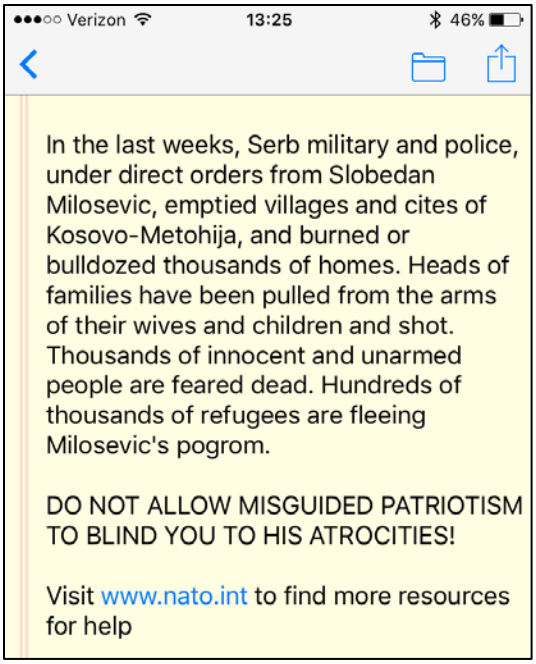


Figure 23. NATO QR code in plain text is the result of Figure 22. It is the word-for-word representation of the original NATO leaflet to the left of the QR code that was scanned. In addition to the plain text, an active hyperlink is also provided which will direct traffic to NATO's website. This enables unique capabilities for building MOEs.

3. Visual Data Channel

When conducting IO messaging, a product using images that contain data like QR codes allow for a few unique capabilities. First, they are very distinct images and once exposure to the technical concept of QR code scanning has been achieved, they are immediately recognizable to anyone who has prior exposure to the concept. Secondly, as has been demonstrated in Figures 17 and 21, there is an ability to overlay another imagine overtop or even within the pixels. The pixels are not limited to black and white, but can also vary in color and combination of images within. The images within can create knowledge of what information or service the QR code contains and lends credibility of the QR code, making users feel more comfortable to scan the code. Figure 24 shows a QR code depicting the YouTube colors and logo as well as the results from the scan. This QR code demonstrates the capability of directly connecting the user to a link or website by simply scanning the code with a QR code scanning application. This particular QR

code immediately directs the user to the video “QR Code generator by Unitag – Tutorial” in English. After opening the link as a result of scanning, the user simply has to touch the play button on the screen and the video starts playing. Figure 25 is an example of how the image of the Twitter logo can be created within the pixels. It also shows the resulting direct connection to the Twitter website where the Tweet “I just created a QR Code using @scanovatech QR Generator http://bit.ly.scnvqrcode” is ready for the user to post to their personal Twitter account. Simply with the push of a button, the user can post the Tweet without typing a single character.

The visual nature allows the message to remain present for longer periods of time than information presented over loudspeaker, radio, television, or other audio channels. Allowing a message to remain present in the physical dimension for a longer period of time will increase the probability of exposure to more members of the desired target audience. This visual nature of QR codes also links back to the covert in the open concept, as the image is static and does not emit any form of energy that is detectable without a visual observer within line-of-sight. Another benefit of the visual nature is that once the QR code is in place, if so chosen, they are capable of creation with no link back to the group or organization that creates and places the QR code. This is obviously contrary to the capability of placing definable images within the pixels, but shows the versatility of applications within the visual nature of QR codes.

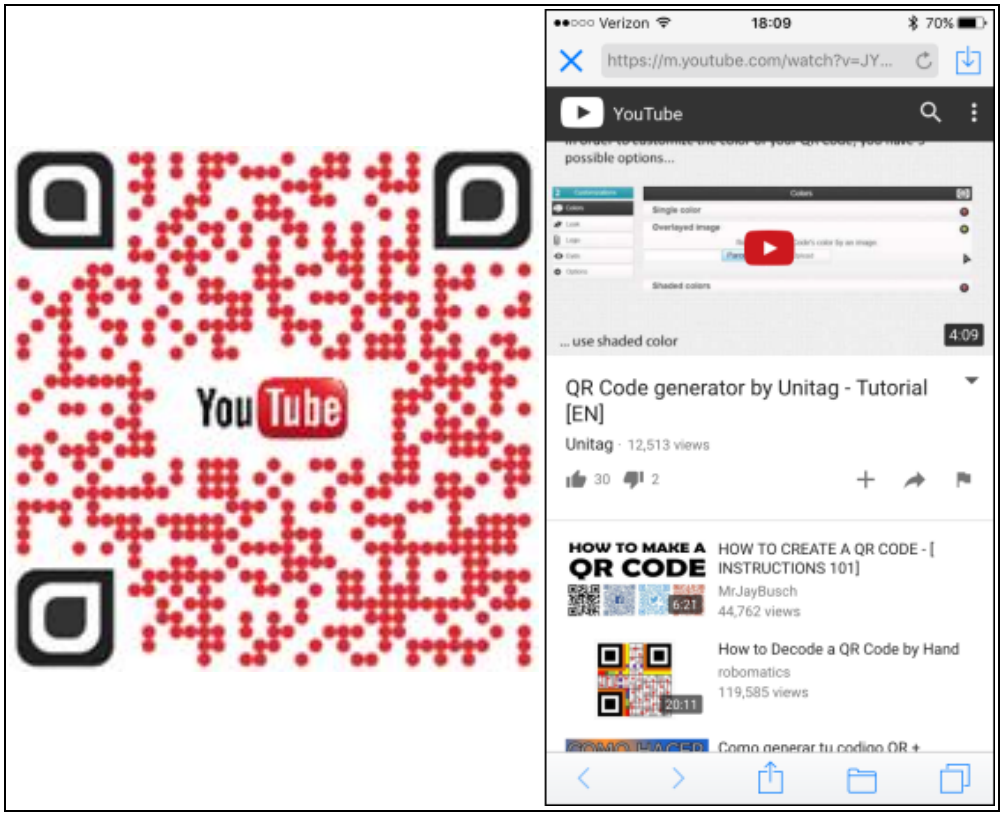


Figure 24. The YouTube QR code shows this direct link to video as a result of scan. Source: Postman (2011).

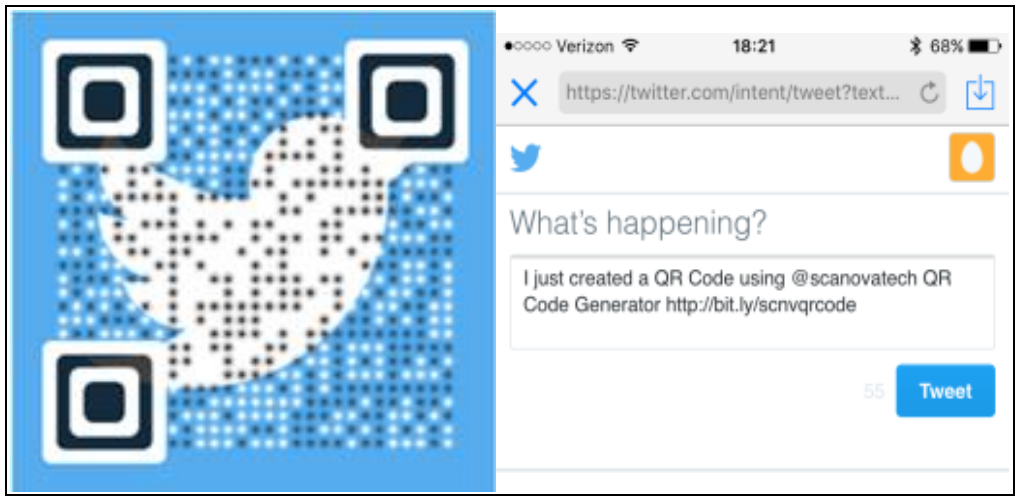


Figure 25. The Twitter logo integration into QR code and result in identifiability of the QR code and shows the result of the scan. Source: Postman (2011).

4. Universally Unique Identifier (UUID)

Universally unique identifiers (UUID) are a 32-byte hexadecimal number that is unique to every generated code. A number this large is so unique that you would not be able to generate an unique number could be generated at a rate of 1,000,000,000 UUIDs per second for one year and the probability of a duplicate is under 50%. Each living person could be assigned 600,000,000 UUIDs and the probability of duplication is still 50% (Online GUID Generator, n.d.). The concept behind this is to be able to assign a unique number to many different individual items. Each item can be given a different and specific code with a very low probability of duplication. The generation and implementation of UUIDs is governed by the Request for Comments (RFC) 4122. A specific and unique is possible for assignment to each QR code that is created in order to track a specific item or message that the QR code is assigned to.

5. Identify Friendly, Foe, Neutral (IFFN)

The identification features that can be associated with QR codes through data analytics discussed in Chapter III, lead to the ability to identify the recipients of messaging products. When the identification of recipients integrates with the ability to identify or assign identity to individuals from anonymous data then the intelligence communities and IO practitioners are able to classify target audiences as friendly, foe, or neutral. Identifying different target audiences is beneficial to measuring the performance of messaging resulting in the ability to achieve better message effectiveness. This is because the narratives associate with a message, which is not necessarily the same for each audience since the influence, effect, or behavioral change desired usually differs between audiences. An effect on a foe is to surrender without fighting, whereas the effect for a neutral audience is avoiding support to the enemy's actions. Separating and identifying audiences is essential for truly measuring performance of the messaging, and when evaluating the message's effectiveness. Since messaging narratives differ between audiences, identification of audiences during evaluation of the effects allows for exclusion of unintended effects from the MOE evaluation. Analysis of the separated audiences allow for early identification of the unintended effects on the campaign.

Identification of friendly, foe, and neutral is not limited to the MOE and MOP portions of IO campaigns. Data analytics offer the capability to geo-locate where each QR code scan is physically conducted. The details of how this is possible are outside scope of this thesis but can be explored for further application purposes, however much of the capabilities to geo-locate fall within the realm of the cyber operations IRC, since it requires analyzing Internet routing and traffic characteristics to identify location. Conducting and utilizing geo-location with the identification features in QR codes for the groups or individuals creates more refined capabilities for military targeting in intelligence, IO, and ground forces communities. A known enemy target's physical location is pinpointed when the identifying characteristics of his or her known device surface through the analytics provided by the scanning of messaging product with an associated QR code. Similarly, QR code related pamphlets and leaflets will then track how far the physical product spreads throughout the area of operations with the geo-location features. This becomes beneficial if a product is interesting enough for an enemy combatant to grab the product and pass it through his or her chain of command. Each scan of the product will lead to a new physical geo-location of that specific product, which then leads to the ability to track the travel routes taken as well as location of potential key enemy individuals. The uses of geo-location features that are associated to the individual messaging product have more potential benefits than currently realized.

E. OBSERVE, ORIENT, DECIDE, ACT (OODA) APPLIED TO INFORMATION OPERATIONS (IO)

Understanding the potential interaction between friendly, foe, and neutral is essential for any successful IO campaign, however this interaction is never as simple as is represented on paper. A perfect example of the complexities comes from the former commander of International Security Assistance Force (ISAF), General Stanley A. McChrystal, when he was briefed the slide in Figure 26 during his time leading American and NATO forces in Afghanistan. The slide design is to convey the American military strategy and the complexity of the interaction of all elements of the war in one not so simple slide. The slide fails to portray any reasonable path to understanding of the operating environment. General McChrystal emphasized such complexity by reacting,

"When we understand that slide, we'll have won the war" (Bumiller, 2010). Similarly, when we understand the interaction between target audiences and IO practitioners, we will have successful IO campaigns. Given the steady incremental understanding demonstrated through the evolution/revolution of direct marketing, the potential evolution/revolution of directed Information Operations is much more predictable and better understood.

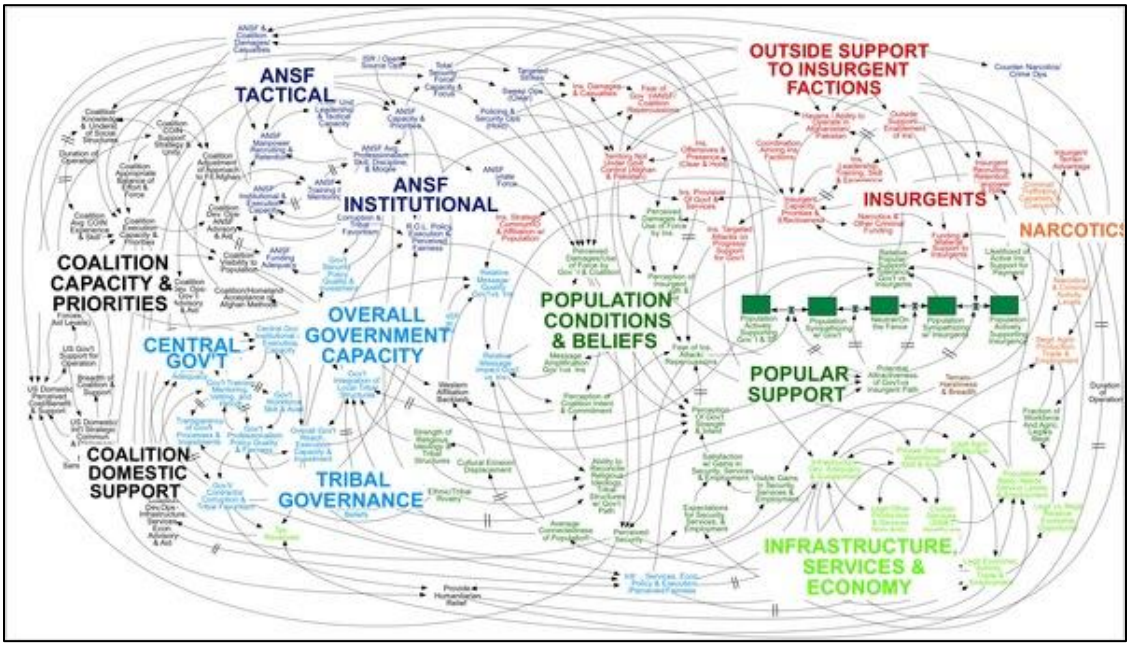


Figure 26. This figure shows "simple" complexity of the Afghanistan operating environment. Source: Bumiller (2010).

1. OODA Loop Principles

The Observe, Orient, Decide, Act (OODA) loop was created by United States Air Force (USAF) Fighter Pilot Colonel John Boyd as a way to explain the decision-making process of pilots in air combat. Commonly in the fighter pilot community, a pilot will observe his opponent first then orient himself against that opponent. Once oriented the pilot decides what action to take against his opponent, which leads to observing the result of that action and forcing the loop's process again. The goal of the OODA loop in the application of fighter pilots is to outperform the opponent and get inside the opponent's

OODA loop. In other words, make the fighter pilot's own OODA loop process faster and tighter to the point where the opponent's OODA loop is not able to keep up and they can no longer react to the actions of the fighter pilot. The linkage from the opponent's act to observe is essentially broken. For the OODA loop's original concept, speed is the central advantage. Figure 27 shows the process.

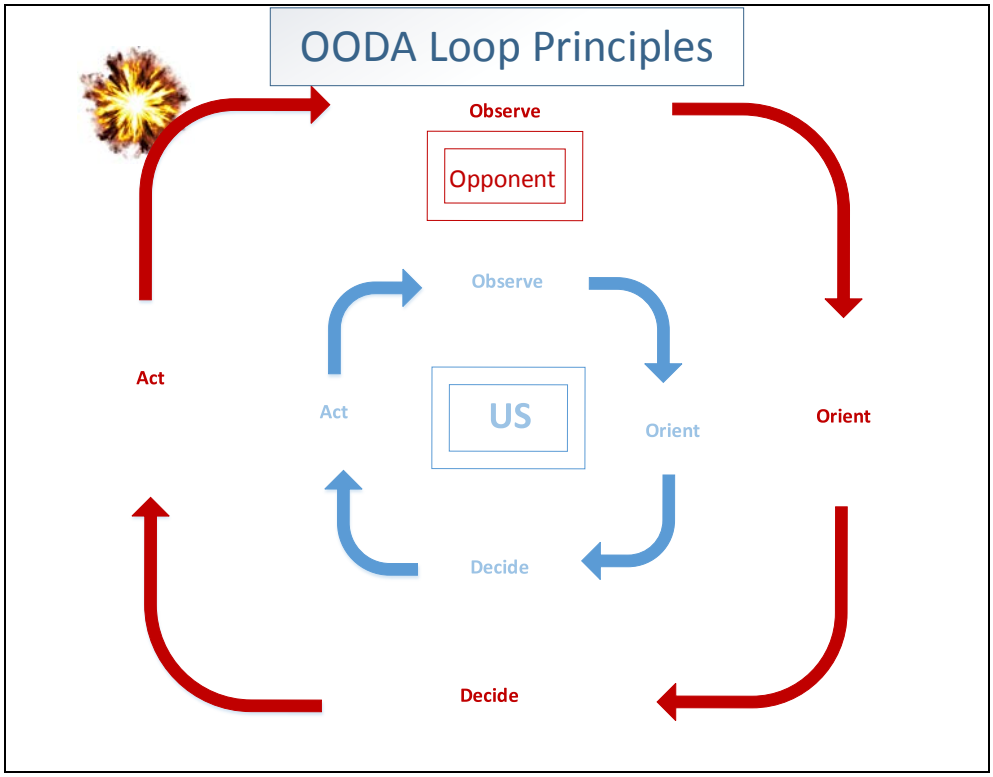


Figure 27. Examining the OODA loop process principles, especially for combat, shows that shorter cycle times mean "getting inside opponent's OOD loop" and are a critical concept for controlling the pace and dominating conflict.

The basic concept of the OODA loop is simple and applicable to many different situations and applications. Its application is relevant to how a NFL quarterback makes pre-snap adjustments, or how a teacher adjusts a lesson plan in the middle of a lecture based upon the students' reaction to the concepts being taught. Smith took Boyd's OODA loop and applied it within the action-reaction cycle described in *Effects-Base Approach to Operations*, as shown in Figure 28. This application of the OODA loop concept inside an

effects oriented observation, which is what IO is designed to achieve; effects, influence, or behavioral change. The Orient step and Decide step are within the cognitive domain. It is interesting to see the overlap of the orient and decide steps in Figure 28, because it shows the importance of orientation within the decision-making process.

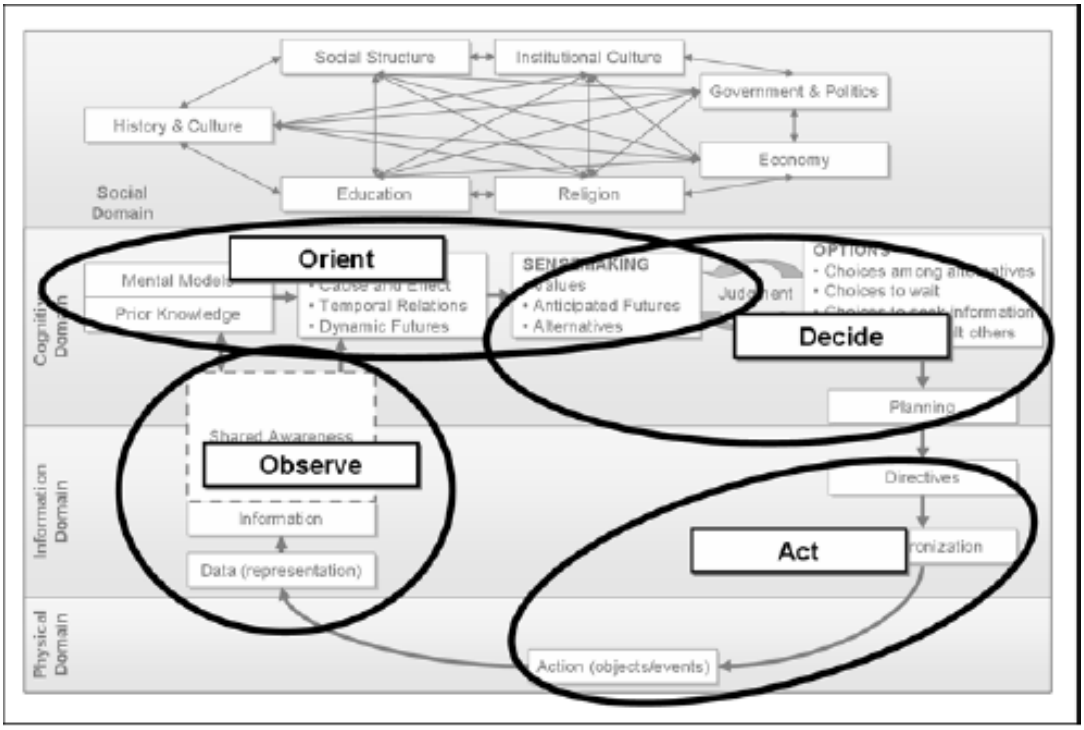


Figure 28. Examining the OODA versus Action-Reaction Cycle results in integration. Source: Smith (2006).

Military application has kept the concept of the OODA loop typically simple. However, in 1996 while Col Boyd presented for one of his last times to military decision makers, the OODA loop was not as simple, and it began to show the inherent complexity of the decision-making process. The Observe step gains feedback through both the Decide and Act steps, and allows feed directly into the Orient stage and out to the Decide or potentially straight to the Act stage. Figure 29 represents this newer concept of the OODA loop. The OODA loop is a beneficial tool to represent the information flow of messaging narratives within the complex information environment that IO practitioners operate within.

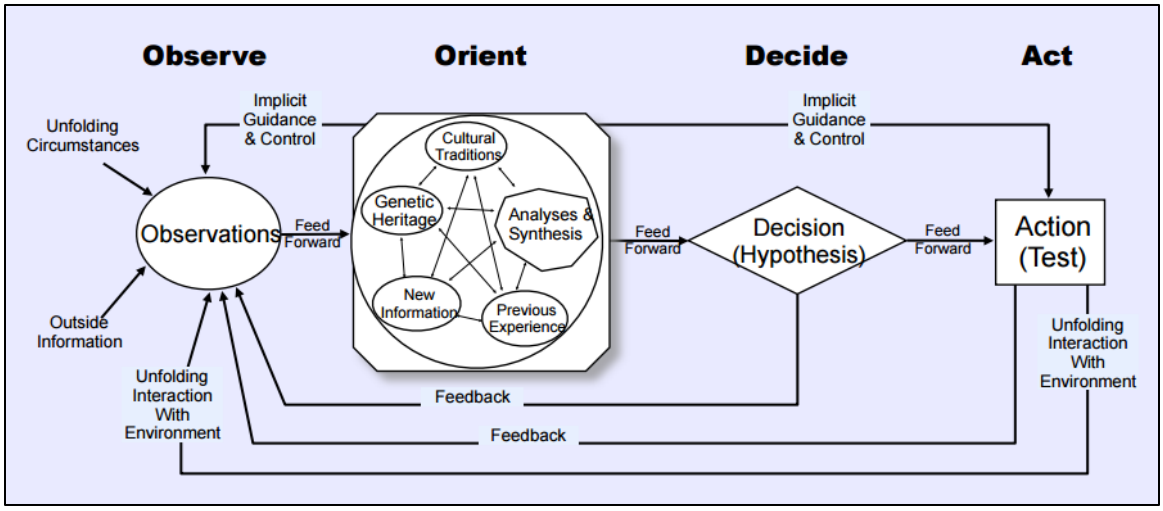


Figure 29. Boyd's final OODA loop concept is more complex than originally thought. Source: Boyd (1996).

2. IO Practitioner Perspective

First, before using QR codes, the IO perspective of the OODA loop of a IO practitioner who is disseminating a product, i.e., a traditional leaflet or pamphlet that does not have the ability to provide the sort of feedback that a product with QR code and data connectivity offers is presented. The deficiency of feedback will lead to weak messaging and the lack of ability in efficiently measuring effectiveness and performance of the message. Figure 30 shows the weakness of current IO capabilities to measure IO messaging of target audiences through traditional metrics, such as ground collection of atmospherics and intelligence from the human interaction with target audiences. The weakness is also attributed to the timeliness of current feedback mechanisms provided by the IRC. Once practitioners release an IO product, the Act step of the OODA loop, they will shift immediately into the Observe step in order to see the effects of the message. With a lack in the ability to immediately observe and gain direct feedback from the interaction with the IO product, the shift from Observe to Orient becomes weak. This leads to a weaker Decide step than desired, and ultimately affects the ability to adjust a previously released message through dissemination of new products in order to achieve the desired effects on the target audience. In effect, actions are decided upon repeatedly with no effective feedback.

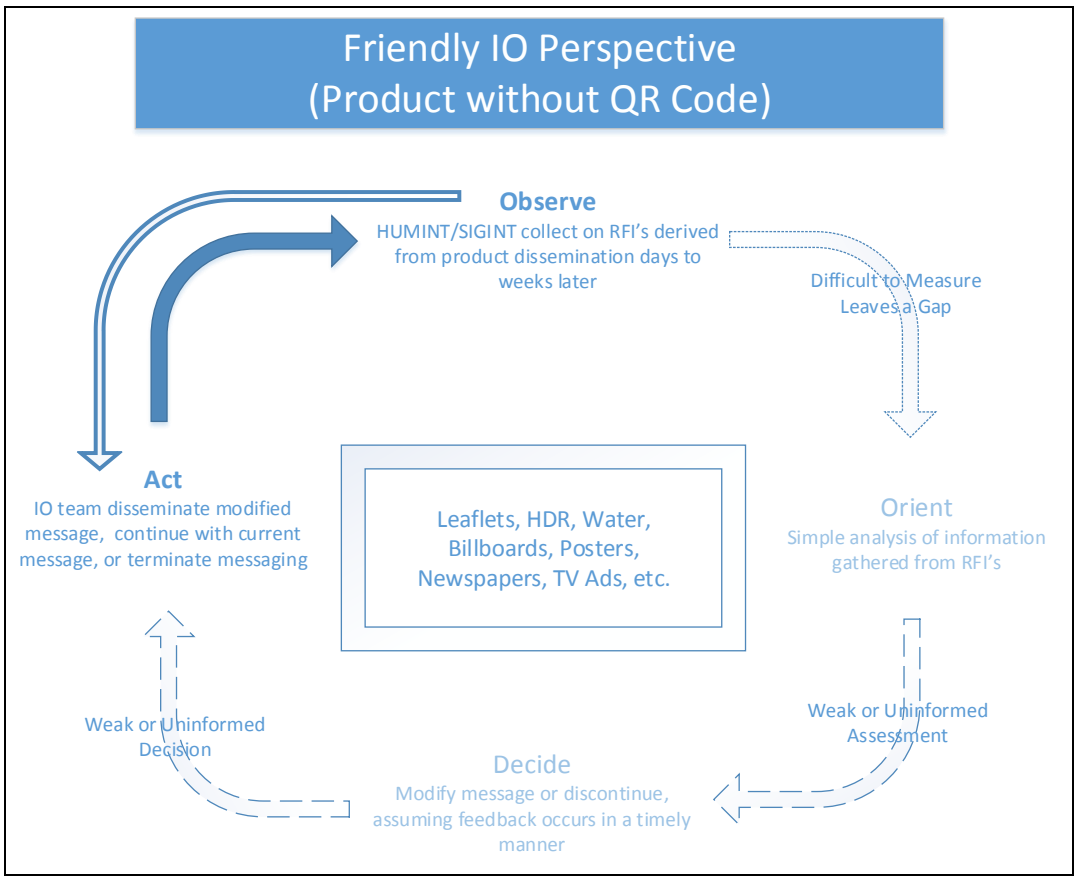


Figure 30. The IO Practitioner's OODA loop without QR code as a data channel is incomplete and open-ended, not providing direct feedback from target audiences.

The change in the IO practitioner's OODA loop when disseminating a product to the target audience that has a QR code printed on it, or a similar technology that enables direct and immediate feedback, shown in Figure 31. Establishing the optical communication channel using cyber and web-related analysis technologies, which QR code technology provide assists members of the target audience to create a feedback channel that makes the linkage between the act of product dissemination to the observation of the target audience's reaction to the product's message more accurate, timely, and valuable. When this feedback channel is established, the Observe step is now as efficient as when a fighter pilot visually observes the actions of his opponent flying in combat with him. Increased capability to observe, results in an improved ability to orient the feedback, leading to knowledge of the feedbacks physical origin and to ability to

identify whether the audience is friend, foe, or neutral. The ability to analyze whether the message reaches the correct audience and is beginning to produce the desired effect, influence, or behavioral change through cyber-based analytics allows for decision making in the follow-on iteration of the OODA loop decision-making process. The increase in timeliness and quality of feedback on the effectiveness and performance of the message will allow for IO practitioners to stay ahead of negative or unintended effects by adjusting messaging to terminating messaging before more damage is done.

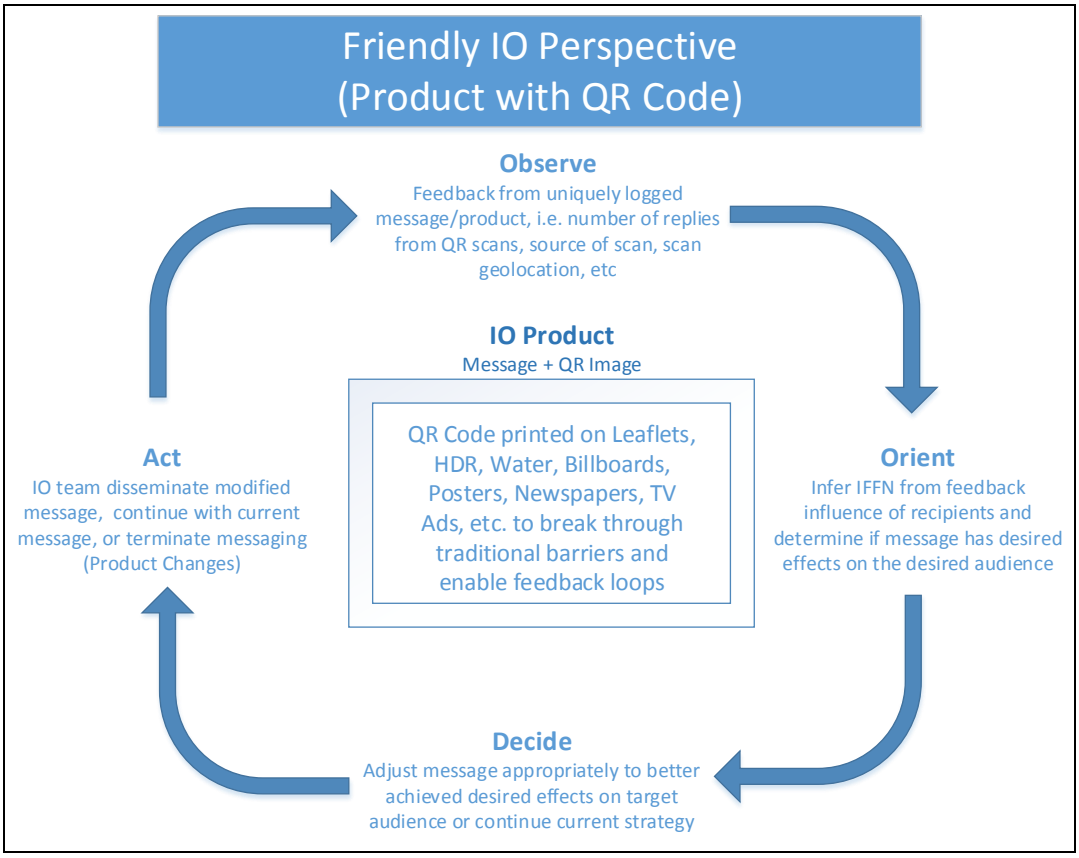


Figure 31. The IO Practitioner's OODA loop with QR code as a feedback channel becomes more valuable and provides opportunity for feedback channels.

3. Target Audience (TA) Perspective

The target audience (TA) also has their own OODA loop associated with the IO products dissemination both as individuals and in aggregate. Figure 32 depicts the target

audience's OODA loop. The target audience sees and scans the product that has the QR code printed on it. Whether or not the populace chooses to interact after this point, message delivery feedback is still provided back to the originators of the product. If there is an option to present to download an application or interact via a web browser or other cyber means, then interacting or not interacting is a form of observable feedback provided by the benefits of enhanced QR code technology. Strictly, from the action of observing the product through scanning of the QR code, IO practitioners have a greater visibility into potential effectiveness of their message.

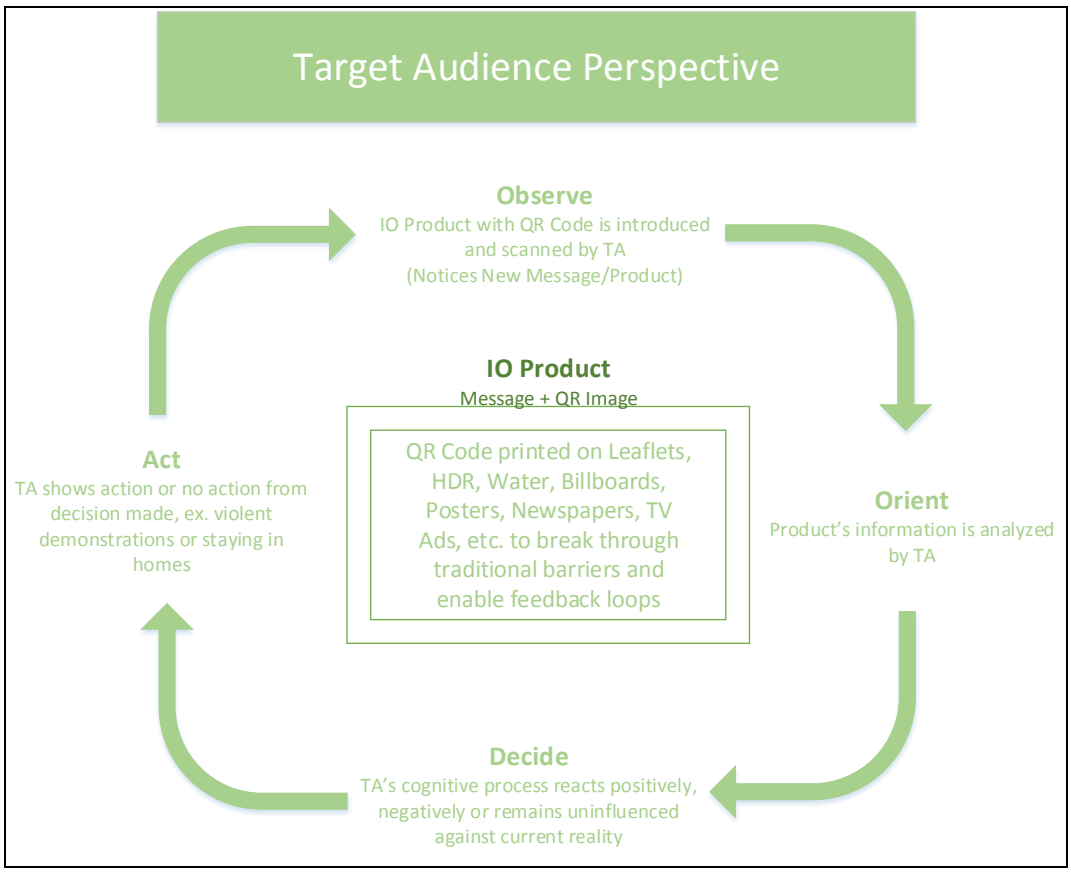


Figure 32. The target audience's OODA loop for a product using a QR code helps to show potential influence.

4. Interaction between Loops Becomes Detectable and Actionable

The fighter pilot scenario associated with the original concept of Col Boyd's OODA loop shows that the purpose is to process through the loop faster than the

opponent does in order to break their loop process. In this IO concept of the OODA loop, the objective is not to break the target audience's OODA loop, but to insert influence into the target audience's loop in order to obtain a desired behavior or effect. The loop of the IO practitioners links in two places with the target audience's loop. Figure 33 shows the interaction between the two loops as well as where the loops connect to each other. The IO practitioner's Act step feeds into the target audience's Observe step. This is how the influence is achieved, the interaction of these two steps.

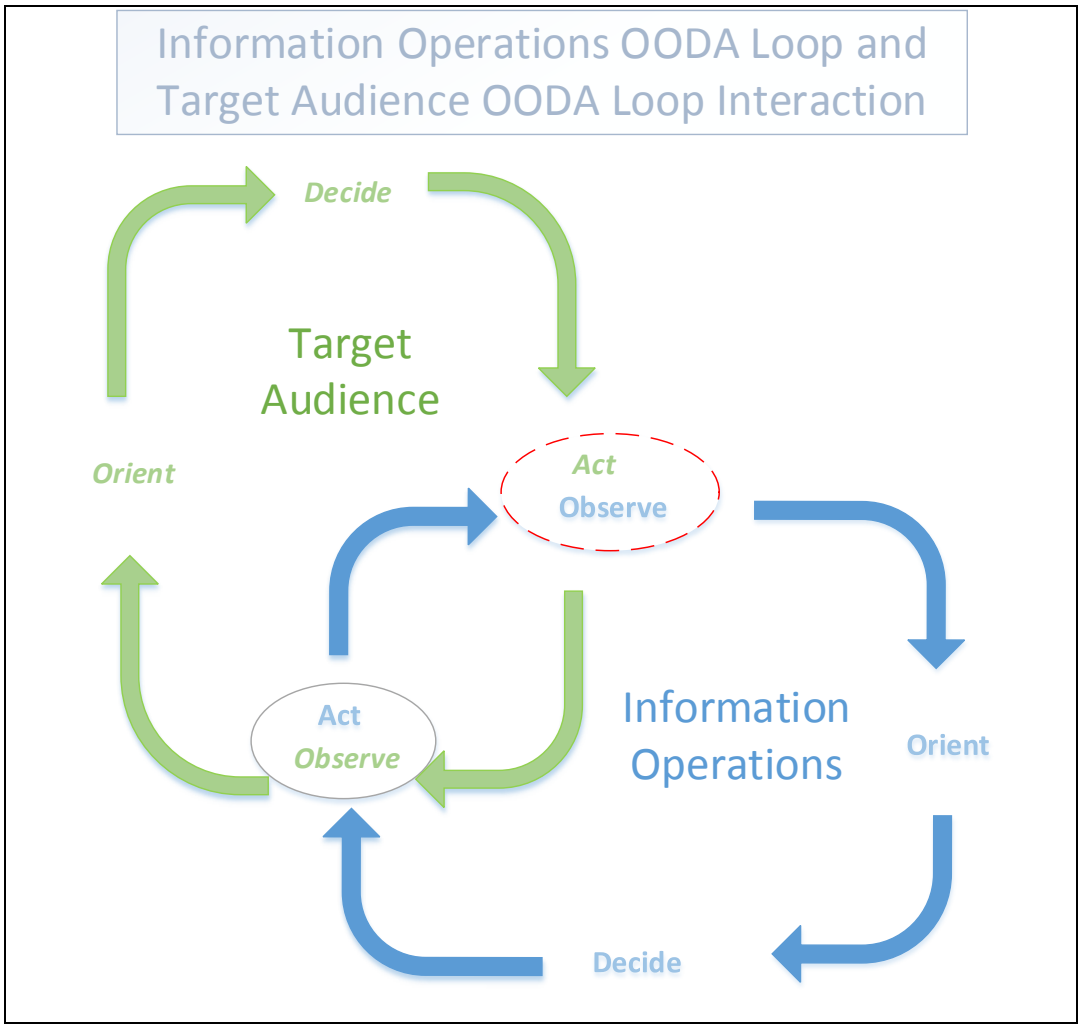


Figure 33. The interaction of the target audience and IO Practitioner OODA loops brings clarity to the current issue in MOE observations. IO Practitioner's actions are observed by Target Audience, while Target Audience's actions are observed by IO Practitioners.

However, two loops or circles that intersect, by nature, cannot intersect in just a single place. Therefore, there must be another portion where the two OODA loops intersect. In Figure 33, the second intersection point is encircled by a dashed red oval. This is where the target audience's Act step, or reaction to the product's message, interacts with the IO practitioner's Observe step to begin a follow-on iteration of the OODA loop process. Currently this step is where the weak link in measuring effectiveness of IO messaging lies.

The weak link is incredibly important to identify. IO practitioners are attempting to influence how the target audience orients themselves to the information provided by the message presented to the target audience in their information environment. When this is achieved, the target audience will act in the manner that the IO practitioners desire. This cannot occur without proper orientation to the message itself. The act is a result of the decision that is influenced by the observation. An inability to observe the desired act of the target audience means that it becomes incredibly more difficult to influence the Orient stage of the target audience, which leads them to the decision to act. Without proper orientation, the desired influence is not possible.

F. INFORMATION OPERATIONS (IO) DIRECT FEEDBACK CHANNEL

In order to develop a stronger link to target audience reactions, concepts will be combined to provide a better idea of how to establish the direct feedback channel for IO practitioners to observe the effectiveness and performance of the message. Since it has been stated that the ability to measure the intangible nature of the cognitive aspect of human decision making is incredibly difficult, then providing a direct feedback channel for those humans (to whom cognitive process is targeted) to directly interact with means an increase of accuracy in measuring the effects, enhanced MOPs and a decrease in the difficulty of gaining the feedback.

Printing QR codes onto IO products or totally replacing traditional IO products with QR images helps individuals to create a direct feedback channel to IO practitioners via web-based applications and analytics. Even placing QR codes onto physical objects like water bottles, humanitarian rations, or the side of a building turn everyday objects

into IO messaging platforms with a direct feedback channel. This channel is established when the target audience scans the QR code from any mobile device that has connectivity to a cellular or wireless network that allows for data transmission. When the QR code is scanned, the related technology that has been associated with, or programmed into, the QR code begins to collect information about the device's characteristics and identification features, as well as the geo-location of the scan via Internet routing and traffic characteristics. This data is able to be combined with other intelligence processes to identify individual or groups.

The individual interaction of the user with the product that they see after the QR code is scanned also provides feedback to the IO practitioner through MOEs and enhanced MOPs. The link has been established but the ability to analyze the effectiveness and performance of the message is now created. The individual that is interacting with the platform presented by the QR code, like a survey, website or application, provides direct feedback to IO messaging by answering questions or even just clicking on links. Surveys can be administered over the QR code link, which allows for direct feedback from the target audience to the IO practitioners. Another example is an application that provides the target audience with some form of interactive entertainment or relevant and useful service. Analysis of how long the individual interacts with the product is also valuable information indicative of effectiveness and performance. The number of times the product is shared over social media or from that person's device can also be an indicator of how effective, through positive or negative language associated with the share, and the performance of the message. Through other cyber related capabilities, further analysis and monitoring, such as geo-location via location services of applications, is possible to continue measuring the effectiveness and performance of the message. Providing a platform that has connectivity to data transfer creates an ability to interact directly with the user.

G. SUMMARY

Due to the shortfalls within current IO messaging capabilities and techniques, the ability to measure the effectiveness of the messaging is currently lacking. The MOEs

assigned to specific IO effects tend to be difficult to measure and the MOPs are deficient in accuracy due to the one-way nature of most messaging. QR codes offer application for many different IRC, not just in MISO related messaging products. However, the combination of cyber capabilities enables the ability to gain direct feedback channels from the optical communication channel that is QR codes due to their visual nature. The idea that the IO practitioner's OODA loop directly interacts with the target audience's OODA loop not only in the dissemination of the message but in the observation of the reaction to the message by the target audience, leads to the necessity to view the messaging process as a bidirectional interaction process. This bidirectional interaction requires the direct feedback channel that the capabilities that QR codes combined with other cyber and web-enabled capabilities offer.

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSIONS

Currently, communications signals within the RF range of the EMS can be intercepted without much effort, and since the adversary Electronic Warfare technologies are advancing quickly, these signals are quite easily exploited by enemy capabilities. Technology has advanced to the point of being able to triangulate the origin of the transmitted signal. This can then become problematic when trying to maintain the element of surprise or secrecy during a covert operation, planned attack, when the adversary forces have the capability to restrict the RF range of the EMS especially during ship-to-shore movement of amphibious operations. The necessity for optical communications as a bidirectional channel for communication is now apparent. From this concept flows the use idea the QR codes offer a bidirectional communications capability.

While most of the works prior researched on QR code relates strictly to optical communication there has been no mention its potential use in Information Operations (IO). There are potential uses for QR code and optical communications employment during amphibious operations as well as in the IO IRC, specifically intelligence, MISO, deception, cyber operations, civil affairs, and public affairs. The implementation of the QR codes can lead to significantly enhanced abilities for messaging target audiences by providing a direct feedback channel or loop to measure the effectiveness of the messaging.

First the idea of the QR codes being an optical communication channel is important. This provides for the concept for a two-way communications capability via QR codes. Next the concepts of data collection and personalized advertising provided by direct marketing must be utilized. The ability to collect data from a simple online purchase, advertisement click, or link visited enables advertising and marketing agencies to analyze this data and in turn see how effective their campaigns are. If the advertisements do not seem to be working, the firms are provided data and reason to adjust. From this data, they are able to also adjust personalized advertising to the target

group based upon interest and feedback shown via purchases and data traffic analysis. These direct marketing techniques are possible through the use of the QR code's optical communication channel and potential connectivity to communications networks. A broader messaging capability will be provided by the scanning of a QR code that directly links to websites or videos, as well as the ability to analyze the individuals and groups scanning the QR codes. Ultimately, the capability that QR codes provide for a direct feedback channel for IO messaging via an optical communications channel will allow for a better-connected and more-efficient Marine Corps and IO community through more accurate, effective, and timely MOEs and enhanced MOPs.

B. RECOMMENDATIONS FOR FUTURE WORK

1. Image Overlay Tool for QR Creation

The use of FEC when creating QR codes is a beneficial asset, however as many current QR code creation websites already offer the ability to integrate simple logos or shapes into the creation process, the need to use FEC for manually overlaying images should be investigated. Potentially an image overlay tool can be created where more complex logos and emblems can be integrated during the creation process rather than after the QR code has been created, which will require a lesser degree of FEC.

2. Alternative Optical Communications Channels

While QR codes do offer a new capability for optical communications, during the research Li-Fi, OWC and other free-space optical communications technologies where investigated. More research into the development of other optical communications channels for military application as alternatives to RF communications will might yield interesting concepts for current communications dilemmas.

3. Identify Friendly, Foe, Neutral (IFFN) Combat Capability

QR codes have application outside amphibious operations and IO campaigns. The use of QR codes to identify and track individuals, vehicles or equipment has potential for application within physical security. The use of unman aerial vehicles (UAVs) to scan an area to keep it secure becomes an option when all friendly personnel and vehicles have a

QR code physically displayed atop their heads or roofs. The concept of universally unique identifier (UUID) can be applied to these QR codes as well. When imagery is transmitted, a system has the ability to analyze images for QR code-like imagery and then process the QR code image. This allows for passive identification of individuals on the battlefield without the use of a blue force tracker or similar RF-transmitted tracking devices and acts as a force multiplier. Further exploration of this concept is suggested.

4. QR Code Data Analytics

The ability to conduct analytics via the scan of a QR code by a device connected to a network was referenced within this thesis. Proving this concept and identifying weaknesses through application of this are recommended. Further, attempts to separate multiple scans by different users to provide analysis of users will yield beneficial information for future research and application.

5. QR Code Applications Research

Research into the potential application avenues of QR codes should be conducted, and experimentation of each application. Currently this thesis shows examples of the ability to directly link QR codes directly to social media communities like YouTube and Twitter. Research into the benefits of directly linking to social media, Wi-Fi networks, contact information, etc., has the potential to lead to new applications for alternative access avenues and other tactical implications. The specific concept of geo-location needs to be further explored in order to assess the benefits thereof.

6. Malicious QR Code

The capability that QR codes offer as an avenue into a network or system for offensive cyber operations was briefly discussed in this thesis. Further research at a classified level will yield the potential application for more cyber capabilities offered by QR code scanning. Gaining access can be difficult for cyber operations, but a stagnant and passive QR code does not typically register in the minds of individuals has a harmful vector.

7. Mobile Application Downloads

Many of the MOE and MOP enhancements come via geo-location based analytics. Mobile applications that target audiences can download offer a potential channel for further collection and analytics of target audiences if incorporated into IO messaging products. Research into potential uses for mobile applications in IO messaging is recommended.

8. Enhanced Measures of Performance (MOP)

While much focus was given to attempting to enhance the capabilities for MOE collection, through this research it was identified that the delivery accuracy and measurements of URL-linked QR codes and other web-based products allows for enhanced performance measurements. Further research into the benefits of enhanced MOPs is recommended.

9. Direct Marketing Specialties

A more in depth research of the specialty areas of direct marketing should be conducted. While traditional marketing might not be applicable to a combat environment for IO, the benefits of direct marketing are clear. A major goal of direct marketing is to gain a measurable response. It takes aim at advertising in ways and mediums that provide a measurable response or better known within military terms as the MOE.

10. Election Marketing and Populace Analytics

During conversation, discussing other potential market analysis, election campaign marketing and analysis was brought up. The idea of electoral analysis feedback through current election campaign marketing has the potential to open or reveal different techniques for measuring the atmospherics of a target audience in order to obtain a baseline and detect any change in attitude.

11. Previous Marketing Concept Failures within IO

Potentially a deeper look into how marketing tactics have been implemented into past IO communities could yield a better understanding of how direct marketing differs.

The differences will potentially overcome the failures of past implementations. For example, how does the direct feedback and measuring that data collection and analysis offer make it far more effective now than when only using traditional marketing techniques.

12. IO Research Development Test & Evaluation (RDT&E) 30-year Strategic Recommendations

The conduct of this work resulted in the following assessment to useful future efforts in IO by Dr. Don Brutzman and Steven Iatrou.

- Information Operations (IO) is a broad integrating strategy including all Information-Related Capabilities to affect decisions.
- Navy/USAF focus on IO effects is currently Electronic Warfare (EW), ElectroMagnetic Maneuver Warfare (EMMW), Spectrum Management and Cyberspace.
- USMC/USA focus also includes effects on populace, typically accomplished through a variety of interpersonal communications.
- A current Naval gap is limited understanding and ability to exploit the full potential effects and influence of IO.
- An important goal is integration of joint operations across EM, Cyber and cognitive spaces.
- RDT&E goals for IO need to focus on sociological and psychological effects on populations of interest. This is primarily a social challenge, catalyzed by communications pathways. (personal communication, May 3, 2016)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. SUMMARY OF INFORMATION-RELATED CAPABILITIES (IRC)

This appendix is taken from the related work of Edward Lipositz's master's thesis, which is to be published during the same period as this thesis.

The following definitions have been adapted from Joint Publication 3–13, *Information Operations* in order to provide a concise introduction to the IRC. For more detailed explanations, please refer to the aforementioned publication.

- Strategic Communications (SC)- a whole of government approach [that is facilitated by interagency coordination.] [SC engages] key audiences through the use of coordinated programs, plans, themes, messages, and products synchronized with the actions of all instruments of national power.

- Public Affairs (PA)- comprises public information, command information, and public engagement activities directed toward both the internal and external publics with interest in DOD. External publics include allies, neutrals, adversaries, and potential adversaries. When addressing external publics, opportunities for overlap exist between PA and IO.

- Civil-Military Operations (CMO)- [the execution of] functions normally provided by the local, regional, or national government, placing them into direct contact with civilian populations. CMO activities establish, maintain, influence, or exploit relations between military forces, governmental and nongovernmental civilian organizations and authorities, and the civilian populace in a friendly, neutral, or hostile operational area in order to achieve U.S. objectives.

- Cyberspace Operations (CO)- the employment of cyberspace capabilities where the primary purpose is to achieve objectives in or through cyberspace. Cyberspace capabilities, when in support of IO, deny or manipulate adversary or potential adversary decision making, through targeting an information medium (such as a wireless access point in the physical dimension), the message itself (an encrypted message in the information dimension), or a cyber-persona (an online identity that facilitates communication, decision making, and the influencing of audiences in the cognitive dimension).

- Information Assurance (IA)- necessary to gain and maintain information superiority. [IA is employed] to protect infrastructure in order to ensure its

availability, to position information for influence, and for delivery of information to the adversary.

- Space Operations- support IO through the space force enhancement functions of intelligence, surveillance, and reconnaissance; missile warning; environmental monitoring; satellite communications; and space-based positioning, navigation, and timing.

- Military Information Support Operations (MISO)- planned operations to convey selected information and indicators to foreign audiences to influence their emotions, motives, objective reasoning, and ultimately the behavior of foreign governments, organizations, groups, and individuals. MISO focuses on the cognitive dimension of the IE.

- Military Deception (MILDEC)- actions executed to deliberately mislead adversary decision makers, creating conditions that will contribute to the accomplishment of the friendly mission.

- Operations Security (OPSEC)- a standardized process designed to meet operational needs by mitigating risks associated with specific vulnerabilities in order to deny adversaries critical information and observable indicators. OPSEC identifies critical information and actions attendant to friendly military operations to deny observables to adversary intelligence systems.

- Electronic Warfare (EW)- securing and maintaining freedom of action in the electromagnetic spectrum for friendly forces while exploiting or denying it to adversaries.

- Key Leader Engagements- deliberate, planned engagements between U.S. military leaders and the leaders of foreign audiences that have defined objectives, such as a change in policy or supporting [the commander's] objectives. These engagements can be used to shape and influence foreign leaders at the strategic, operational, and tactical levels, and may also be directed toward specific groups such as religious leaders, academic leaders, and tribal leaders; e.g., to solidify trust and confidence in U.S. forces.

Additional IRC include, but are not limited to: physical attack, physical security, counter-intelligence, Combat Camera, Special Technical Operations, and Defense Support to Public Diplomacy. (Lipositz, 2016)

APPENDIX B. WIKIPEDIA QUICK REACTION (QR) CODE WEBPAGE

> Wikipedia is an online open-content collaborative encyclopedia; that is, voluntary association of individuals and groups working to develop a common resource of human knowledge. The structure of the project allows anyone with an Internet connection to alter its content. Please be advised that nothing found here has necessarily been reviewed by people with the expertise required to provide you with complete, accurate or reliable information.
>
> That is not to say that you will not find valuable and accurate information in Wikipedia; much of the time you will. However, Wikipedia cannot guarantee the validity of the information found here. The content of any given article may recently have been changed, vandalized or altered by someone whose opinion does not correspond with the state of knowledge in the relevant fields. ("Wikipedia: General Disclaimer," n.d.)

The remainder of this appendix is taken directly from the QR code Wikipedia page ("QR code," n.d.) and converted to PDF by the Wikipedia's organic capabilities. It is a non-standard reference and is included in the interest of completeness for the reader to understand the capabilities of QR Code technology. By no means is this intended to be a de-facto reference for the development, implementation, or operations of an optical QR code communication system. It is provided here as a user reference.

QR code

This article is about the type of barcode. For the mathematical coding theory, see Quadratic residue code.

QR code (abbreviated from **Quick Response Code**)

QR code for the URL of the English Wikipedia Mobile main page

is the trademark for a type of matrix barcode (or two-dimensional barcode) first designed for the automotive industry in Japan. A barcode is a machine-readable optical label that contains information about the item to which it is attached. A QR code uses four standardized encoding modes (numeric, alphanumeric, byte/binary, and kanji) to efficiently store data; extensions may also be used.[1]

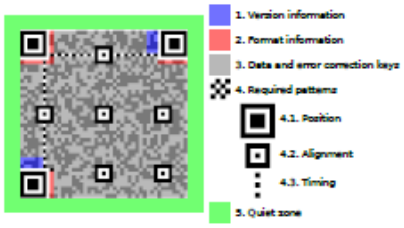
The QR code system became popular outside the automotive industry due to its fast readability and greater storage capacity compared to standard UPC barcodes. Applications include product tracking, item identification, time tracking, document management, and general marketing.[2]

A QR code consists of black modules (square dots) arranged in a square grid on a white background, which can be read by an imaging device (such as a camera, scanner, etc.) and processed using Reed–Solomon error correction until the image can be appropriately interpreted. The required data are then extracted from patterns that are present in both horizontal and vertical components of the image.[2]

1 History

The QR code system was invented in 1994 by Denso Wave. Its purpose was to track vehicles during manufacture; it was designed to allow high-speed component scanning.[3] Although initially used for tracking parts in vehicle manufacturing, QR codes now are used in a much broader context, including both commercial tracking applications and convenience-oriented applications aimed at mobile-phone users (termed mobile tagging). QR codes may be used to display text to the user, to add a vCard contact to the user's device, to open a Uniform Resource Identifier (URI), or to compose an e-mail or text message. Users can generate and print their own QR codes for others to scan and use by visiting one of several paid and free QR code generating sites or apps. The technology has since become one of the most-used types of two-dimensional barcode.[4]

2 Standards



Structure of a QR code, highlighting functional elements

There are several standards that cover the encoding of data as QR codes:[5]

- October 1997 – AIM (Association for Automatic Identification and Mobility) International[6]
- January 1999 – JIS X 0510
- June 2000 – ISO/IEC 18004:2000 *Information technology – Automatic identification and data capture techniques – Bar code symbology – QR code* (now withdrawn)
  Defines QR code models 1 and 2 symbols.
- 1 September 2006 – ISO/IEC 18004:2006 *Information technology – Automatic identification*

and data capture techniques – QR code 2005 bar code symbology specification
Defines QR code 2005 symbols, an extension of QR code model 2. Does not specify how to read QR code model 1 symbols, or require this for compliance.

- 1 February 2015 – ISO/IEC 18004:2015 *Information – Automatic identification and data capture techniques – QR Code barcode symbology specification*
  Renames the QR Code 2005 symbol to QR Code and adds clarification to some procedures and minor corrections.

At the application layer, there is some variation between most of the implementations. Japan's NTT DoCoMo has established de facto standards for the encoding of URLs, contact information, and several other data types.[7] The open-source "ZXing" project maintains a list of QR code data types.[8]

3 Uses

A QR code used on a large billboard in Japan, linking to the sagasou.mobi website

QR codes have become common in consumer advertising. Typically, a smartphone is used as a QR code scanner, displaying the code and converting it to some useful form (such as a standard URL for a website, thereby obviating the need for a user to type it into a web browser). QR code has become a focus of advertising strategy, since it provides a way to access a brand's website more quickly than by manually entering a URL.[9][10] Beyond mere convenience to the consumer, the importance of this capability is that it increases the conversion rate (the chance that contact with the advertisement will convert to a sale), by coaxing interested prospects further down the conversion funnel with little delay or effort, bringing the viewer to the advertiser's website immediately, where a longer and more targeted sales pitch may lose the viewer's interest.

Although initially used to track parts in vehicle manufacturing, QR codes are now (as of 2012) used over a much wider range of applications, including commercial tracking, entertainment and transport ticketing, product/loyalty marketing (examples: mobile couponing where a company's discounted and percent discount can be captured using a QR code decoder which is a mobile app, or storing a company's information such as address and related information alongside its alpha-numeric text data as can be seen in Yellow Pages directory), and in-store product labeling. It can also be used in storing personal information for use by organizations. An example of this is Philippines National Bureau of Investigation (NBI) where NBI clearances now come with a QR code. Many of these applications target mobile-phone users (via mobile tagging). Users may receive text, add a vCard contact to their device, open a URI, or compose an e-mail or text message after scanning QR codes. They can generate and print their own QR codes for others to scan and use by visiting one of several pay or free QR code-generating sites or apps. Google had a popular API to generate QR codes,[11] and apps for scanning QR codes can be found on nearly all smartphone devices.[12]

QR codes storing addresses and URLs may appear in magazines, on signs, on buses, on business cards, or on almost any object about which users might want information. Users with a camera phone equipped with the correct reader application can scan the image of the QR code to display text, contact information, connect to a wireless network, or open a web page in the telephone's browser. This act of linking from physical world objects is termed hardlinking or object hyperlinking. QR codes also may be linked to a location to track where a code has been scanned. Either the application that scans the QR code retrieves the geo information by using GPS and cell tower triangulation (aGPS) or the URL encoded in the QR code itself is associated with a location.[13]

Recruiters have started placing QR codes in job advertisements,[15] while applicants have started sporting it in their CVs and visiting cards.[15]

In June 2011, The Royal Dutch Mint (*Koninklijke Nederlandse Munt*) issued the world's first official coin with a QR code to celebrate the centenary of its current building and premises. The coin can be scanned by a smartphone and link to a special website with contents about the

QR codes have been used and printed on train tickets in China since 2010.[14]

historical event and design of the coin.[16] In 2014, the Central Bank of Nigeria issued a 100-naira banknote to commemorate the centennial of its existence. It is the first banknote to incorporate the QR code into its design. When scanned with an internet-enabled mobile device, the code goes to a website which tells the centenary story of Nigeria.[17]In 2015, the Central Bank of the Russian Federation issued a 100-ruble note to commemorate the annexation of Crimea by the Russian Federation. It contains a QR code into its design, and when scanned with an internet-enabled mobile device, the code goes to a website that details the historical and technical background of the commemorative note. In 2008, a Japanese stonemason announced plans to engrave QR codes on gravestones, allowing visitors to view information about the deceased, and family members to keep track of visits.[18]

Psychologist Richard Wiseman was one of the first authors to include QR codes in a book, in *Paranormality: Why We See What Isn't There* (2011), allowing his readers to follow-up on paranormal claims by accessing his research through the codes.[19]

3.1 Mobile operating systems

QR codes can be used on various mobile device operating systems. These devices support URL redirection, which allows QR codes to send metadata to existing applications on the device. Many paid or free apps are available with the ability to scan the codes and hard-link to an external URL.

3.2 URLs

URLs aided marketing conversion rates even in the pre-smartphone era, but during those years faced several limitations: ad viewers usually had to type the URL and often did not have a web browser in front of them when they first viewed the ad. The chances were high that they would forget to visit the site later, not bother to type a URL, or forget what URL to type. Semantic URLs decreased these risks but did not eliminate them. Some of these disadvantages to URL conversion rates are fading away now that smartphones are putting web access and voice recognition in constant reach, with QR code providing the URL for instant access.

3.3 Virtual stores

During the month of June 2011, according to one study, 14 million mobile users scanned a QR code or a barcode. Some 58% of those users scanned a QR or barcode from their homes, while 39% scanned from retail stores; 53% of the 14 million users were men between the ages of 18 and 34.[20] The use of QR codes for "virtual store" formats started in South Korea,[21] and Argentina,[22] but is currently expanding globally.[23] Walmart, Procter & Gamble and Woolworths have already adopted the Virtual Store concept.[24]

3.4 Code payments

QR codes can be used to store bank account information or credit card information, or they can be specifically designed to work with particular payment provider applications. There are several trial applications of QR code payments across the world.[25][26]

In November 2012, QR code payments were deployed on a larger scale in the Czech Republic when an open format for payment information exchange - a Short Payment Descriptor - was introduced and endorsed by the Czech Banking Association as the official local solution for QR payments.[27]

QR codes are commonly used in the field of cryptographic currencies, particularly those based off and including Bitcoin.[28] Payment addresses, cryptographic keys and transaction information are often shared between digital wallets in this way.[29]

3.5 Website login

QR codes can be used to log in into websites: a QR code is shown on the login page on a computer screen, and when a registered user scans it with a verified smartphone, they will automatically be logged in. Authentication is performed by the smartphone which contacts the server. Google tested such a login method in January 2012.[30]

3.6 Funerary use

In 2008, Ishinokoe in Yamanashi Prefecture, Japan began to sell tombstones with QR codes produced by IT DeSign, where the code leads to a virtual grave site of the deceased.[31][32][33] Other companies have begun implementing QR codes into tombstones[34] and in 2014 the

Jewish Cemetery of La Paz in Uruguay, began implementing QR codes for tombstones.[35]

3.7 Encryption

Japanese visa with a QR code (content is enciphered)

Encrypted QR codes, which are not very common, have a few implementations. An Android app,[36] for example, manages encryption and decryption of QR codes using the DES algorithm (56 bits).[37] The Japanese immigration system uses encrypted QR codes when issuing visa in passports[38] as shown in the figure to the right.

4 Design

Unlike the older, one-dimensional barcodes that were designed to be mechanically scanned by a narrow beam of light, a QR code is detected by a 2-dimensional digital image sensor and then digitally analyzed by a programmed processor. The processor locates the three distinctive squares at the corners of the QR code image, using a smaller square (or multiple squares) near the fourth corner to normalize the image for size, orientation, and angle of viewing. The small dots throughout the QR code are then converted to binary numbers and validated with an error-correcting algorithm.

4.1 Storage

The amount of data that can be stored in the QR code symbol depends on the datatype (*mode*, or input character set), version (1, …, 40, indicating the overall dimensions of the symbol), and error correction level. The maximum storage capacities occur for 40-L symbols (version 40, error correction level L):[4][39]

Here are some sample QR code symbols:

- Version 1 (21×21). Content: "Ver1"
- Version 2 (25×25). Content: "Version 2"
- Version 3 (29×29). Content: "Version 3 QR Code"
- Version 4 (33×33). Content: "Version 4 QR Code, up to 50 char"
- Version 10 (57×57). Content: "VERSION 10 QR CODE, UP TO 174 CHAR AT H LEVEL, WITH 57X57 MODULES AND PLENTY OF ERROR CORRECTION TO GO AROUND. NOTE THAT THERE ARE ADDITIONAL TRACKING BOXES"
- Version 25 (117×117 enlarged to 640x640)
- Version 40 (177×177). Content: 1,264 characters of ordinary/ASCII text: A description of QR codes taken from an early version of this Wikipedia article

4.2 Error correction

Damaged but still decodable QR code

Codewords are 8 bits long and use the Reed–Solomon error correction algorithm with four error correction levels. The higher the error correction level, the less storage capacity. The following table lists the approximate error correction capability at each of the four levels:

Example of a QR code with artistic embellishment that will still scan correctly thanks to error correction

In larger QR symbols, the message is broken up into several Reed–Solomon code blocks. The block size is chosen so that at most 15 errors can be corrected in each block; this limits the complexity of the decoding algorithm. The code blocks are then interleaved together, making it less likely that localized damage to a QR symbol will overwhelm the capacity of any single block.

Due to error correction, it is possible to create artistic QR codes that still scan correctly, but contain intentional errors to make them more readable or attractive to the human eye, as well as to incorporate colors, logos, and other features into the QR code block.[41][42]

It is also possible to design artistic QR codes without reducing the error correction capacity by manipulating the underlying mathematical constructs.[43][44]

4.3 Encoding

The format information records two things: the error correction level and the mask pattern used for the symbol. Masking is used to break up patterns in the data area that might confuse a scanner, such as large blank areas or misleading features that look like the locator marks. The mask patterns are defined on a grid that is repeated as necessary to cover the whole symbol. Modules corresponding to the dark areas of the mask are inverted. The format information is protected from errors with a BCH code, and two complete copies are included in each QR symbol.[2]

The message dataset is placed from right to left in a zigzag pattern, as shown below. In larger symbols, this is complicated by the presence of the alignment patterns and the use of multiple interleaved error-correction blocks.

- Meaning of format information
- Message placement within a QR symbol
- Larger symbol illustrating interleaved blocks

Four-bit indicators are used to select the encoding mode and convey other information. Encoding modes can be mixed as needed within a QR symbol.

After every indicator that selects an encoding mode is a length field that tells how many characters are encoded in that mode. The number of bits in the length field depends on the encoding and the symbol version.

Alphanumeric encoding mode stores a message more compactly than the byte mode can, but cannot store lower-case letters and has only a limited selection of punctuation marks, which are sufficient for rudimentary web addresses. Two characters are coded in an 11-bit value by this formula:

$$V = 45 \times C_1 + C_2$$

4.4 Decoding example

The following images offer more information about the QR code.

- 1 — Introduction
- 2 — Structure
- 3 — Layout & Encoding
- 4 — Levels & Masks
- 5 — Protocols

5 Variants

Micro QR code is a smaller version of the QR code standard for applications where symbol size is limited. There are four different versions (sizes) of Micro QR codes: the smallest is 11×11 modules; the largest can hold 35 numeric characters.[45]

IQR code is an alternative to existing QR codes developed by Denso Wave. IQR codes can be created in square or rectangular formations; this is intended for situations where a rectangular barcode would otherwise be more appropriate, such as cylindrical objects. IQR codes can fit the same amount of information in 30% less space. There are 61 versions of square IQR codes, and 15 versions of rectangular codes. For squares, the minimum size is 9x9 modules; rectangles have a minimum of 19x5 modules. IQR codes add error correction level S, which allows for 50% error correction.[46] IQR Codes have not yet been given an ISO specification, and only proprietary Denso Wave products can create or read IQR codes.[47]

Model 1 QR code is an older version of the specification. It is visually similar to the widely seen model 2 codes, but lacks alignment patterns.

- Micro QR code example

- Micro QR code functional regions
- Model 1 QR code example
- Model 1 QR code functional regions

6 License

The use of QR codes is free of any license. The QR code is clearly defined and published as an ISO standard.

Denso Wave owns the patent rights on QR codes, but has chosen not to exercise them.[5] In the USA, the granted QR code patent is US 5726435, and in Japan JP 2938338. The European Patent Office granted patent "EPO 0672994". to Denso Wave, which was then validated into French, UK, and German patents, all of which are still in force as of November 2011.

The word **QR code** itself is a registered trademark of Denso Wave Incorporated.[48] In UK, the trademark is registered as E921775, the word "QR Code", with a filing date of 03/09/1998.[49] The UK version of the trademark is based on the Kabushiki Kaisha Denso (DENSO CORPORATION) trademark, filed as Trademark 000921775, the word "QR Code", on 03/09/1998 and registered on 6/12/1999 with the European Union OHIM (Office for Harmonization in the Internal Market).[50] The U.S. Trademark for the word "QR Code" is Trademark 2435991 and was filed on 29 September 1998 with an amended registration date of 13 March 2001, assigned to Denso Corporation.[51]

7 Risks

The only context in which common QR codes can carry executable data is the URL data type. These URLs may host JavaScript code, which can be used to exploit vulnerabilities in applications on the host system, such as the reader, the web browser or the image viewer, since a reader will typically send the data to the application associated with the data type used by the QR code.

In the case of no software exploits, malicious QR codes combined with a permissive reader can still put a computer's contents and user's privacy at risk. This practice is known as "attagging", a portmanteau of "attack tagging".[52] They are easily created and can be affixed over legitimate QR codes.[53] On a smartphone, the reader's permissions may allow use of the camera, full Internet access, read/write contact data, GPS, read browser history, read/write local storage, and global system changes.[54][55][56]

Risks include linking to dangerous web sites with browser exploits, enabling the microphone/camera/GPS, and then streaming those feeds to a remote server, analysis of sensitive data (passwords, files, contacts, transactions),[57] and sending email/SMS/IM messages or DDOS packets as part of a botnet, corrupting privacy settings, stealing identity,[58] and even containing malicious logic themselves such as JavaScript[59] or a virus.[60][61] These actions could occur in the background while the user is only seeing the reader opening a seemingly harmless web page.[62] In Russia, a malicious QR code caused phones that scanned it to send premium texts at a fee of US$6 each.[52]

8 Extension

Samples of the High Capacity Colored 2-Dimensional (HCC2D) code: (a) 4-color HCC2D code and (b) 8-color HCC2D code.

Researchers have proposed a new High Capacity Colored 2-Dimensional (HCC2D) Code, which builds upon a QR code basis for preserving the QR robustness to distortions and use colors for increasing data density (even if at this stage it is still in prototyping phase). The HCC2D code specification is described in details in Querini et al. (2014),[63] while techniques for color classification of HCC2D code cells are descripted in details in Querini and Italiano (2014),[64] which is an extended version of Querini and Italiano (2013).[65]

Introducing colors into QR codes requires addressing additional issues. In particular, during QR code reading only the brightness information is taken into account, while HCC2D codes have to cope with chromatic distortions during the decoding phase. In order to ensure adaptation to chromatic distortions which arise in each scanned code, HCC2D codes make use of an additional field: the Color Palette Pattern. This is because color cells of a Color Palette Pattern are supposed to be distorted in the same way as color cells of the Encoding Region. Replicated color palettes are used for training machine learning classifiers.

9 See also

- CueCat
- QRpedia
- SnapTag
- SPARQCode

- Touchatag

10 References

[1] "QR Code features". Denso-Wave. Archived from the original on 2012-09-15. Retrieved 3 October 2011.

[2] "QR Code Essentials". Denso ADC. 2011. Retrieved 12 March 2013.

[3] Borko Furht (2011). *Handbook of Augmented Reality*. Springer. p. 341. ISBN 9781461400646.

[4] "QR Code — About 2D Code". Denso-Wave. Archived from the original on 2012-09-15. Retrieved 3 October 2011.

[5] "QR Code Standardization". *QR Code.com*. Denso-Wave. Archived from the original on 2012-09-15. Retrieved 23 April 2009.

[6] "AIM Global Online Store". Aimglobal.org. Archived from the original on 2012-09-15. Retrieved 23 April 2009.

[7] "Synchronization with Native Applications". NTT DoCoMo. Archived from the original on 2012-09-05. Retrieved 17 February 2009.

[8] "Barcode Contents". *zxing – A rough guide to standard encoding of information in barcodes*. Archived from the original on 2012-05-30. Retrieved 17 February 2009.

[9] Rimma Kats (23 January 2012). "Starbucks promotes coffee blend via QR codes". Archived from the original on 2012-09-12.

[10] Jenny Lee (4 January 2012). "Tesco's cool QR code advertising campaign". Archived from the original on 2012-07-20.

[11] "Google Chart Tools". Archived from the original on 2012-07-07.

[12] "QR Code Readers for iPhone, Android, Blackberry and Windows Phone 7". Archived from the original on 2012-07-18.

[13] "Geo Tagged QR Codes". Archived from the original on 2012-07-14. Retrieved 27 October 2011.

[14] "QR codes on China's train tickets may leak personal information". *Want China Times*. Retrieved 16 March 2013.

[15] "How to jazz up your CV with QR codes - The Times of India". *The Times Of India*.

[16] "World's first QR code coin website". Archived from the original on 2012-09-15.

[17] "New ₦100 Commemorative Centenary Celebration". Retrieved 10 September 2015.

[18] Novak, Asami (2008-03-23). "Japanese Gravestones Memorialize the Dead With QR Codes". Wired. Retrieved 2013-05-08.

[19] Skepticality (5 July 2011). "Paranormality". Skepticality.com. Retrieved 27 June 2015.

[20] "16 August 2011". Archived from the original on 2012-09-06.

[21] "Tesco QR Code Virtual Store". Archived from the original on 2012-09-15.

[22] "Marketing futurista: ya se puede comprar con la cámara del celular". Archived from the original on 2012-09-15.

[23] "11 November 2010". Archived from the original on 2012-09-15.

[24] "Top 10 QR Code Store examples". Archived from the original on 2012-09-15.

[25] "SCVNGR Unveils QR Code Payment System".

[26] "MasterCard starts piloting QkR mobile payment app".

[27] "Standard No. 26: Format for exchanging the payment information for Czech domestic payments using the QR codes". Czech Banking Association. November 2012.

[28] "FAQ - Bitcoin". Retrieved 10 September 2015.

[29] "Blockchain.info - Bitcoin Wallet - Features". Retrieved 10 September 2015.

[30] "Google testing login authentication via QR codes".

[31] "[redacted]". Retrieved 10 September 2015.

[32] "QR code graves give a "Memorial Window"". *Japan Trends*. Archived from the original on 2 May 2012. Retrieved 10 September 2015.

[33] "[redacted] - [redacted]". Retrieved 10 September 2015.

[34] "Quiring Monuments adds smartphone codes to gravestones". *Puget Sound Business Journal*. 26 April 2011. Retrieved 10 September 2015.

[35] "Uruguayan Jewish Cemetery QRfied" (in Spanish). EL PAIS. 24 March 2014.

[36] "QR Droid". Google. 19 August 2011. Retrieved 5 September 2011.

[37] "Encrypted QR Codes". QR Droid. 24 October 2011. Retrieved 5 September 2011.

[38] "QR Code Usage In Japan". Studio Cliffano. 18 May 2009. Retrieved 18 May 2009.

[39] "Version and Maximum capacity table". Denso-Wave. Archived from the original on 2012-09-15.

[40] "2D Barcode: QR-Code". Archived from the original on 2012-09-15. — TEC-IT

[41] Orli Sharaby (18 October 2010). "Form Meets Function: Extreme Makeover QR Code Edition". Archived from the original on 2012-07-08. Retrieved 29 July 2011.

[42] Hamilton Chan (18 April 2011). "HOW TO: Make Your QR Codes More Beautiful". Archived from the original on 2012-07-10. Retrieved 29 July 2011.

[43] Russ Cox (12 April 2012). "QArt Codes: How to make pictures with QR codes, part II". Archived from the original on 2015-03-21. Retrieved 8 May 2015.

[44] Russ Cox (12 April 2012). "QArt Coder". Retrieved 8 May 2015.

[45] Information technology — Automatic identification and data capture techniques — QR Code 2005 bar code symbology specification, ISO/IEC 18004:2006 cor. 2009, pages 3, 6.

[46] "QR Code Overview & Progress of QR Code Applications" (PDF). Retrieved 26 June 2014.

[47] "iQR Code - QRcode.com - DENSO WAVE". Retrieved 10 September 2015.

[48] "QR Code.com". Denso-Wave. 6 November 2003. Archived from the original on 2012-09-15. Retrieved 23 April 2009.

[49] "UK QR Code Trademark". Archived from the original on 2012-09-15.

[50] "EU QR Code Trademark". Archived from the original on 2012-09-15.

[51] "US QR Code Trademark". Archived from the original on 2012-09-15.

[52] "Jargon Watch", *Wired* **20** (1), January 2012, p. 22.

[53] "Malicious Images: What's a QR Code". SANS Technology Institute. 3 August 2011. Archived from the original on 2012-07-13. Retrieved 31 August 2011.

[54] "Barcode Scanner". Google. 1 June 2011. Archived from the original on 2012-09-15. Retrieved 31 August 2011.

[55] "QR Droid". Google. 19 August 2011. Archived from the original on 2012-09-15. Retrieved 31 August 2011.

[56] "ScanLife Barcode Reader". Google. 24 May 2011. Archived from the original on 2012-09-15. Retrieved 31 August 2011.

[57] "Consumer Alert: QR Code Safety". Better Business Bureau. 23 June 2011. Archived from the original on 2012-07-15. Retrieved 31 August 2011.

[58] "AVG Cautions: Beware of Malicious QR Codes". PC World. 28 June 2011. Archived from the original on 2012-09-07. Retrieved 31 August 2011.

[59] "EvilQR – When QRCode goes bad". AppSec-Labs Blog. 14 August 2011. Archived from the original on 2012-09-15. Retrieved 31 August 2011.

[60] "QR Codes: A Recipe for a Mobile Malware Tsunami". Cyveillance, Inc. 20 October 2010. Archived from the original on 2012-07-28. Retrieved 31 August 2011.

[61] QR Codes hold up to 2.9 KB whereas the smallest known computer virus is about one-tenth that size "The Smallest Virus I Could Manage". Virus Labs and Distribution. 1995. Archived from the original on 2012-09-15. Retrieved 31 August 2011.

[62] "Beware of Malicious QR Codes". ABC. 8 June 2011. Archived from the original on 2012-08-01. Retrieved 31 August 2011.

[63] 2D Color Barcodes for Mobile Phones

[64] Reliability and data density in high capacity color barcodes

[65] Color classifiers for 2D color barcodes

11 Bibliography

- *BS ISO/IEC 18004:2006. Information technology. Automatic identification and data capture techniques. Bar code symbology. QR Code*. Geneva: ISO/IEC. 2000. p. 114.
- *BS ISO/IEC 18004:2006. Information technology. Automatic identification and data capture techniques. QR Code 2005 bar code symbology specification*. London: BSI. 2007. p. 126. ISBN 978-0-580-67368-9.

12 External links

- Official website
- Reed Solomon Codes for Coders – an elaborate tutorial on Wikiversity, covering both QR code structure and the Reed Solomon codes used to encode the data.

13 Text and image sources, contributors, and licenses

13.1 Text

- **QR code** *Source:* https://en.wikipedia.org/wiki/QR_code?oldid=717974390 *Contributors:* AxelBoldt, Rootbeer, Thosp, Michael Hardy, Kku, Julesd, Scott, Andres, Victor Engel, Charles Matthews, Crissov, GPHemsley, Northgrove, Robbot, Hankwang, Sander123, Pigsonthewing, Nurg, SEKIUCHI, Postdlf, Auric, Sheridan, Krugdm, Pengo, Tea2min, Alan Liefting, DocWatson42, Holizz, Inkling, Orangemike, Niteowlneils, Ceejayoz, AlistairMcMillan, Python eggs, Golbez, Vadmium, Zeimusu, Lockeownzj00, Elektron, Squash, Thorwald, Mike Rosoft, Discospinster, Rich Farmbrough, Bert490, Antaeus Feldspar, Pavel Vozenilek, Gronky, Flapdragon, Zubari, VishalB, PatrikR, Smalljim, Polluks, AndrewRH, Hardwick, Pe7er, Conny, Gary, Elpincha, Habsteadk, Diego Moya, Rakerman, Apoc2400, Dankarran, Kocio, Blobglob, Immanuel Giel, Wtshymanski, Bsadowski1, Versageek, Jun-Dai, Bruce89, Simetrical, Woohookitty, Mindmatrix, RHaworth, GVOLTT, Dandv, Daniel Case, Pol098, Spike0xFF, JeremyA, Dmol, GregorB, Isnow, Eyreland, Waldir, Graham87, DePiep, Rjwilmsi, Kouvf, Arisa, Miserlou, Bubba73, The wub, Oliverkeenan, Syced, FlaBot, TiagoTiago, Crazycomputers, Tedder, Daev, Chobot, Antilived, DVdm, Bgwhite, Timmay911, WriterHound, Kakuraty, The Rambling Man, Whoisjohngalt, Alchemy pete, RussBot, Hydrangyrum, Shaddack, Rsrikanth05, NawlinWiki, ENeville, Dforest, Arichnad, Daniel Mietchen, Scs, William Graham, Srowen, Dbfirs, Dissolve, Xpclient, Ninly, Closedmouth, CapitalLetterBeginning, Black-Velvet, Graemel., Fram, Katieh5584, NFG, TrygveFlathen, Triskelios, SmackBot, McGeddon, C.Fred, KelvinMo, Gjs238, CHawke, Mauls, Basseq, Zephyris, Portillo, Ohnoitsjamie, Skizzik, Chris the speller, Thumperward, Ned Scott, Mrchaotica, Rrburke, Addshore, Cybercobra, MichaelBillington, T3h, WhosAsking, Hughespj, Autopilot, Lambiam, Lester, Mobiryder, Wibbble, Tim bates, Accurizer, RichMorin, CredoFromStart, BlindWanderer, Geh, Trounce, TomNor, ISBN, Dl2000, Quaeler, ScwB, T.O. Rainy Day, IvanLanin, UncleDouggie, Goens, Blehfu, Ewulp, AbsolutDan, Nloth, Alfpooh~enwiki, BeenAroundAWhile, Mathsgeek, Juhachi, Muzikman2787, Lentower, Zinjixmaggir, MaxEnt, Pewwer42, Dogman15, Wadkdc, Gogo Dodo, Myscrnnm, Dancter, Luccas, Alaibot, Hontogaichiban, Thijs!bot, Epbr123, Kronos, Steffan.stringer, Davidelit, Ishdarian, N5iln, 24fan24, Anupam, ChrisEich, Mord3n, Marek69, MesserWoland, MichaelMaggs, SusanLesch, Harddavid, Betathetapi545, Hires an editor, The Obento Musubi, WinBot, Widefox, Hansschmucker, Krisguy, Rsocol, StevenMcCoy, Worufu~enwiki, Fasol, Kaywa~enwiki, NapoliRoma, MER-C, Matthew Fennell, Jheiv, Igodard, Greensburger, Paladin656, Hurmata, Kacela, Cweiske, Bongwarrior, VoABot II, Transcendence, Mbarbier, Frankk74, Theroadislong, Sricel3, Miltoncontact, Textorus, Orem0, FisherQueen, Arjun01, Blumin, Anaxial, Glrx, CommonsDelinker, Vox Rationis, -ginkgobiloba-, JamesD'Alexander, Maurice Carbonaro, Stephanwehner, Mlearning, Davidprior, Hcl1023~enwiki, 83d40m, Uofalbany, Sculptorjones, KylieTastic, Joshua Issac, STBotD, Tweisbach, Bonadea, Codetesuki, RVJ, 28bytes, Jericbryledy, VolkovBot, Kriplozoik~enwiki, Jeff G., JohnBlackburne, AlastairIrvine, Ryan032, Philip Trueman, TXiKiBoT, Knowledgebycoop, Wikidemon, Inmonaranja, Wikipedantry, Mbonetti, Wiae, Katimawan2005, Brdali, Staka, Truthanado, HiDrNick, Wla2000, Michael Frind, Legoktm, HybridBoy, Fjurden, Ponyo, Brianfstevenson, Jeallison, SieBot, Nathan, Jerryobject, Pxma, Nopetro, Billy-Buggy, Yerpo, OsamaBinLogin, Erick880, KoshVorlon, Mayalld, Svick, Panicum, Mettakalyanamitta, Martin H., Kallog, Denisarona, Explicit, Beofluff, ClueBot, DVTB, Francydl~enwiki, WurmWoode, Eric Wester, Fadesga, EoGuy, 100percentrecord, Ndenison, AircraftWorld, Der Golem, Trivialist, TimmmmCam, Auntof6, Pg.richard, Kitsunegami, Excirial, Bagworm, Justapersona, Alexbot, Threequarter-ten, CRobClark, Vasco.bonifacio, Lartoven, Rhododendrites, Complicated1, OekelWm, Mikaey, Light show, Nonaeroterraqueous, Berean Hunter, Apparition11, SF007, Vanished user uih38riw4hjlsd, SteelMariner, DumZiBoT, Jordihernandez, XLinkBot, Scribeofargos, Avoided, Jenbsullivan, SilvonenBot, Ynalaka, Lepton6, Iamjamieq, MystBot, Addbot, Leopiccioli~enwiki, Mortense, Toddpurgason, CL, D0762, Zarcadia, Fluffernutter, Denso BHT, Download, LaaknorBot, Alex0987, Graf von Moltke, Tototutu, Favonian, SpBot, SeymourSycamore, ShizzeliFizzle, דוד ש, Seb7, Luckas-bot, Yobot, Adrianlew, Fbudetz, Hopsta, KamikazeBot, Pava, Rhythmcandy, Sweerek, MinorProphet, Renessaince, Komari90, AnomieBOT, Rcpeditor, 1exec1, Götz, Carlozbt, JackieBot, KingJ, Schworak, Materialscientist, Loveonearth, Neurolysis, ArthurBot, Nifky?, Alhasagianttongue, Xqbot, Zhoulikan, Lunakillah, Randowiki, Jchor, Francisco Paiva Junior, Pierredecoubertin, Nasa-verve, GrouchoBot, Qrme, Webapplications, Tannim101, A.amitkumar, GaryJGolden, Cekli829, TerraHikaru, FrescoBot, Remotelysensed, Georgefondue, Primabaker, D'ohBot, Ionutzmovie, Mfwitten, Edu82, Gbruwne, Renart.fox, Amicaveritas, Lococococoloco, Citation bot 1, Xxglennxx, Redrose64, Tesukibeingfree, DrilBot, Alice160190, Joebigwheel, Partyzan XXI, Thewatchdog2012, RedBot, MastiBot, Brakspear, Jandalhandler, Ergotius, Keiyakins, SwiftingSpeed, TobeBot, Mono, Dave Punktilio, Tooncoppens, Vrenator, Dororai, PumaBeest, Webknjaz, Aoidh, Memaster3, Anthony morgan peters, Skakkle, Bobmath, Onel5969, Mean as custard, RjwilmsiBot, Sargdub, Hanky27, TjBot, Ripchip Bot, Lopifalko, Kerrick Staley, EmausBot, John of Reading, WikitanvirBot, TheSophera, Tcoffin88, Dewritech, Lightgunner, GoingBatty, Gimmetoo, Slightsmile, Tommy2010, Winner 42, Princess Lirin, Jackedhacker, Wikipelli, Dcirovic, Wtuvell, Djembayz, AvicBot, ZéroBot, Pabeaufait, Fæ, Ojwilliams8, Daschilling, TonyBorelli, Aborelli, Kilopi, Yoreciv, Espejitosdecolores, Shb0, Chrispi900, Sbmeirow, Brandmeister, Chrisp900, Ishanoval, Schnoatbrax, Champion, Palosirkka, Donner60, Kootje~enwiki, Samxyouxwell, ShayaWiki, Buffavento, Fr33dbr33d, Donnalibra, ChuispastonBot, Charlotte Boersma, Esilence, Criskruijff, Junaid.baloch, Jsgott, Will Beback Auto, ClueBot NG, Horoporo, Zfophf, Qrcodemania, AirWalk009, Golden herring, Jamesnpope, Lew424, Jeff Song, Manubot, Catlemur, Lyla1205, Portland99, Brjodo, Loew Galitz, Jcevallos, O.Koslowski, Mnguru1, Widr, Merlob, StephenDowding, Theopolisme, NeilQR, Smmgeek, Larryscala, Helpful Pixie Bot, CoolAmp, Ateliered, Alanbach, Lf2dcat, Tomhung357, Curb Chain, Siddhant2010, Garygob884, Codezign, Aoidh (Away), BG19bot, Adolushanov, Bmusician, Bookchic831, Itsallup, Impressionsplymouth, M0rphzone, Ess292, Rijinatwiki, Absconded Northerner, Ldinallo, Timfolkes, Frze, Qrcdesigner, Aanddrew22, Mseguin, Michael Barera, Socialmaven1, Gmlandsdowne, Rob392, Jorge005, Jhamak, CustomQRCodes, Mobilead, Pezzo~enwiki, Frizb99, Vasco Bonifácio, Philipjamesbarnes, Kosmastr, Jediknightelectro1997, Chip123456, Wwrthr, BattyBot, Luqmanmaat, Justincheng12345-bot, Marius.radu85, David.moreno72, Testem, Jimw338, Jiovanmelendez, Cyberbot II, ChrisGualtieri, MontyLov, Dagelf, JesseYUNY, YFdyh-bot, SD5bot, Jegan11, Kalzone1, Schmidjd, Janswer, FrankMazza, Batviaship, John Behind The Curve, RobertoVaick, Rotlink, The Anonymouse, BurritoBazooka, Guillerodriguez, Lele287, Uriel Peled, Ekips39, Jgotty, Hawthorn2008, Plinkyedit, Pisteuomen, Hippo.69, AlphaE3, Joshis.wiki, Howicus, Sxs957, Semicircle2012, JimBoff, Hesed9, Legendofthebend, Edyzuadi, Piwaiwaka, Penguin tnki, Panpog1, Thevideodrome, Misterandrade, Comto67, Avishaby, ItamarMar, OnewordTF, Girsuloft, Quenhitran, Todd E Feeley, DrRNC, Paul2520, Carl J. Garcia, 13fifamessi, Rizwannadir, Wills64, Lagoset, Thor4bp, Monkbot, Nishanthc92, Shynya1325, FrankMazza3, Procrastinatingpersona, Andreas295, Ozonesn, Chino8265, Abollypak, Usmansajjad0000, Hsoni92, Mrs. Waterflow, Mr. Doubtbike, Yuck, I hate perrey, Thinhvip, Weiqk, Waleedkalld, Joseph2302, Teaberry Johnson, Wishva de Silva, Kjbanaro, KasparBot, NewHikaru07, ILIKEHOMOS, PeaceForEverybody, David Neil Johnson, Let's bash Patrick Nese!, Finally, memorial day!, Dulaj Udayanga Bandara Kulathunga, Saifulrony88, Rainforestdok, Naeime.karami, Gizmo987, Asksilence, Tostado1993, GSS-1987, Qzd, Pozzreach, H.dryad, Csfandude, Awspindel, EDGEWOOD.SUCKS, Hassaannaeem1978 and Anonymous: 819

13.2 Images

- **File:Commons-logo.svg** *Source:* https://upload.wikimedia.org/wikipedia/en/4/4a/Commons-logo.svg *License:* CC-BY-SA-3.0 *Contributors:* ? *Original artist:* ?
- **File:Extreme_QR_code_to_Wikipedia_mobile_page.png** *Source:* https://upload.wikimedia.org/wikipedia/commons/b/b5/Extreme_QR_code_to_Wikipedia_mobile_page.png *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* Qrc-designer
- **File:Folder_Hexagonal_Icon.svg** *Source:* https://upload.wikimedia.org/wikipedia/en/4/48/Folder_Hexagonal_Icon.svg *License:* Cc-by-sa-3.0 *Contributors:* ? *Original artist:* ?
- **File:Hcc2d.png** *Source:* https://upload.wikimedia.org/wikipedia/commons/b/b0/Hcc2d.png *License:* CC BY-SA 4.0 *Contributors:* Own work *Original artist:* Marco.querini
- **File:Imbox_content.png** *Source:* https://upload.wikimedia.org/wikipedia/commons/3/38/Imbox_content.png *License:* PD *Contributors:*
  Derived from Image:Information icon.svg *Original artist:*
  El T (original icon); David Levy (modified design); Penubag (modified color)
- **File:Japan-qr-code-billboard.jpg** *Source:* https://upload.wikimedia.org/wikipedia/commons/3/32/Japan-qr-code-billboard.jpg *License:* CC BY-SA 3.0 *Contributors:* Own work, I took the picture *Original artist:* Nicolas1981
- **File:Japan_Visa_with_QR_code.jpg** *Source:* https://upload.wikimedia.org/wikipedia/en/a/a1/Japan_Visa_with_QR_code.jpg *License:* CC-BY-SA-3.0 *Contributors:*
  i made it by taking photograph
  Original artist:
  Horoporo
- **File:MaxiCode.svg** *Source:* https://upload.wikimedia.org/wikipedia/commons/b/b4/MaxiCode.svg *License:* Public domain *Contributors:* I created this work using the tool found at http://www.tec-it.com/online-demos/tbarcode/barcode-generator.aspx?LANG=en, and converted it to SVG using Inkscape. While the page did specify usage conditions on integrating the barcode creator service into a website, no conditions were placed on the use of individual barcodes created with the service.
  Original artist: Darco at en.wikipedia
- **File:QR_Code_Damaged.jpg** *Source:* https://upload.wikimedia.org/wikipedia/commons/8/8d/QR_Code_Damaged.jpg *License:* CC0 *Contributors:* This file was derived from Wikipedia mobile en.svg:
  Original artist: Wikipedia_mobile_en.svg: brdall.
- **File:QR_Code_Structure_Example_3.svg** *Source:* https://upload.wikimedia.org/wikipedia/commons/1/1d/QR_Code_Structure_Example_3.svg *License:* CC BY-SA 3.0 *Contributors:* This file was derived from QR Code Structure Example 2.svg:
  Original artist: Bobmath
- **File:UPC_A.svg** *Source:* https://upload.wikimedia.org/wikipedia/commons/f/fe/UPC_A.svg *License:* Public domain *Contributors:* Own work *Original artist:* Maly LOLek
- **File:Wikipedia_mobile_en.svg** *Source:* https://upload.wikimedia.org/wikipedia/commons/9/9b/Wikipedia_mobile_en.svg *License:* Public domain *Contributors:* Transferred from en.wikipedia to Commons by Liftarn using CommonsHelper. *Original artist:* brdall
- **File:Z80-Tianjin_-Beijing.jpg** *Source:* https://upload.wikimedia.org/wikipedia/commons/a/a7/Z80-Tianjin_-Beijing.jpg *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* Yaohua2000

13.3 Content license

- Creative Commons Attribution-Share Alike 3.0

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. NETWORK OPTIONAL WARFARE (NOW) QUICK REACTION (QR) CODE FLYER

Figure 34. Flyer from Network Optional Warfare (NOW) website showing QR code streaming capabilities and previous works. Source: Brutzman (2015).

Optical Signaling for Network Optional Warfare (NOW)

https://wiki.nps.edu/display/NOW/Network+Optional+Warfare

Optical Signaling refers to Line of Sight (LOS) information transfer using visual means. Each of these techniques has the potential to significantly reduce vulnerability to detection of electromagnetic (EM) radio emissions.

Quick Reaction (QR) Code Streaming

Quick Reaction (QR) Codes can be used for single messages of various sizes or to create a streaming data channel.

Thesis work

- Lucas, Andrew, Digital Semaphore: Technical Feasibility of QR Code Optical Signaling for Fleet Communications, Master's Thesis, Naval Postgraduate School, June 2013. Received NPS Outstanding Thesis Award.
- Richter, Stephen P., Digital Semaphore: Tactical Implications of QR Code Optical Signaling for Fleet Communications, Master's Thesis, Naval Postgraduate School, June 2013. Received NPS Outstanding Thesis Award.
- Sokol, Christopher R., "A Study on Using Quick Reference Codes in Airport Surface Operations to Reduce Accidents and Incidents While Taxiing," capstone project, Embry-Riddle University, 18 June 2013.

QR Code on King Hall

NPS thesis work in 2013 investigated the possibility of viewing QR codes as a data-signaling mechanism to aircraft. Here are pictures of the completed QR Code on King Hall.

QR Chat

As part of our building an open-source application, here is a video demonstration of our open-source QR Visual Chat application that works without a network. Working nickname: *"Digital Semaphore"* for use in Network Optional Warfare (NOW).

Interested in learning more, or reporting that you've seen the rooftop QR code? Your feedback is welcome at qr@nps.edu, thanks!

http://qr.nps.edu

QR Code on King Hall

QR Visual Chat demo

Additional references

- **Digital Flashing Light (DFL).** New project referring to automation of classic Flashing Light signaling through use of QR Code (Digital Semaphore) streaming techniques.
- TODO: we are interested in obtaining a pair of Navy signal lamps for use in ongoing experimentation.
- Flag Semaphore display and recognition also appears to automatable using digital image analysis techniques.
- Laser and Free-space optical communication

Stay tuned, lots more to follow!

- Examining correspondences and corollaries between radio and optical domains
- Radar-absorbing, carbon-fiber clouds, aka “electronic smoke” (7th Fleet Tests Innovative Missile Defense System)
- Ongoing work comparing Network-Centric Warfare (NCW) and Network-Optional Warfare (NOW) approaches

Contact

All questions and comments are welcome, please let us know what you think.

Don Brutzman, brutzman@nps.navy.mil +1.831.656.2149

LIST OF REFERENCES

Alberts, M. (1997). The Information Age: An anthology on its impact and consequences. [Ebrary version]. Retrieved from http://www.dodccrp.org/files/Alberts_Anthology_I.pdf

Analytics Screenshot (n.d.) [Image]. Retrieved April 20, 2016 from https://www.qrstuff.com/images/analytics_screenshot.png

Barney, C., Dich, A.,& Koufos, D. (2014). *Visible light communication systems*. (bachelor's thesis). Worcester Polytechnic Institute, Worcester, MA. Retrieved from https://www.wpi.edu/Pubs/E-project/Available/E-project-032814-001416/unrestricted/MQP_Report_Final_Draft_3_27_14.pdf

Battelle, J. (2005). *The search: How Google and its rivals rewrote the rules of business and transformed our culture*. New York: Portfolio.

Brutzman, D. (2016, February 17). Optical Signaling. Retrieved June 7, 2016 from https://wiki.nps.edu/display/NOW/Optical+Signaling/

Bumiller, E. (2010, April 26). We have met the enemy and he is PowerPoint. *The New York Times*. Retrieved from http://www.nytimes.com

Chiang, W., Chhajed, D., Hess, J. (2003) Direct Marketing, indirect profits: A strategic analysis of dual- channel supply-chain design. *Management Science 49(1)*:1-20. Retrieved from http://dx.doi.org/10.1287/mnsc.49.1.1.12749

Chilik. (2011, August 14). EvilQR- When QRCode goes bad [Article]. Retrieved from https://appsec-labs.com/portal/security-assessment-of-mobile-qr-readers-%E2%80%93-a-comparison

Cirino, J. (December, 2011). QR Codes in education [PowerPoint]. Retrieved from http://www.slideshare.net/jcirino/qr-codes-in-education-12970707

Cities and coastal areas. (n.d.). Retrieved May 19, 2016 from http://www.unep.org/urban_environment/issues/coastal_zones.asp

Conway, M. (2014, January 28). The evolution of Super Bowl advertising. Retrieved from https://www.pressboxonline.com/2014/01/28/the-evolution-of-super-bowl-advertising

Department of Defense. (2013, May 2). Information Operations (IO) (DOD Directive 3600.01). Washington, DC: Author.

Dholakia, S. (2016, February 1). What 50 years of Super Bowl advertising has taught us. Retrieved from https://www.clickz.com/2016/02/01/what-50-years-of-super-bowl-advertising-has-taught-us

Digital semaphore: QR codes for tactical signaling. (2012). Retrieved from NPS Savage Defense website: https://savagedefense.nps.navy.mil/qr/index.php/Report

Flee. (n.d.). Examining the history and processes of direct and interactive marketing [Lecture notes]. Retrieved May 25, 2016 from http://web.calstatela.edu/faculty/flee/www/mkt448/www/Lectures/SG01.pdf

Friedman, H. (n.d.). PSYOP against Milosevic's Yugoslavia. Retrieved March 29, 2016 from http://www.psywarrior.com/BosniaHerb.html

Google Analytics. (n.d.). Retrieved May 18, 2016 from https://www.google.com/analytics/standard/

Haas, Harald. (2013, April 19). High-speed wireless networking using visible light. *SPIE Newsroom*. doi:10.1117/2.1201304.004773.

Kline, J., & Englehorn, L. (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER): Warfare innovation workshop (WIW) 2011 after action report*. Naval Postgraduate School, Monterey, CA. Retrieved from: http://calhoun.nps.edu/bitstream/handle/10945/33985/CRUSER%20WIW%202011%20Final%20Report.pdf?sequence=4&isAllowed=y

Kieseberg, P., Leithner, M., Mulazzani, M., Munroe, L., Schrittwieser, S., Sinha, M., & Weippl, E. (2010). QR code security. *Eighth International Conference on Advances in Mobile Computing and Multimedia*. 430–435. doi: 10.1145/1971519.1971593

Li-Fi is a bidirectional, high speed and fully networked wireless communication technology. (n.d.) [Blog post]. Retrieved May 10, 2016 from http://qrznow.com/li-fi-is-a-bidirectional-high-speed-and-fully-networked-wireless-communication-technology/

Lipostiz, E. (2016, June). *The relevance of armor in the Information Environment*. (Unpublished master's thesis). Naval Postgraduate School. Monterey, CA.

Longfellow, H. W. The Landlord's tale; Paul Revere's ride. Henry Wadsworth Longfellow Maine Historical Society. Retrieved April 28, 2016 from http://www.hwlongfellow.org.

Lucas, A. (2013, June). *Digital Semaphore: Technical feasibility of QR code optical signaling for fleet communications*. (Master's thesis, Naval Postgraduate School, Monterey, CA). Retrieved from Calhoun https://calhoun.nps.edu/handle/10945/34699

Manes, S. (2000, 06). Private lives? not ours! PC World, 18, 312. Retrieved from http://libproxy.nps.edu/login?url=http://search.proquest.com.libproxy.nps.edu/docview/231417874?accountid=12702

Marketing. (2009). In *Merriam-Webster's dictionary* (11th ed.). Springfield, MA: Merriam-Webster.

Online GUID Generator. (n.d.).. Retrieved June 13, 2016 from https://www.guidgenerator.com/

Performance (n.d.) [Image]. Retrieved March 9, 2016 from http://www.qrcode.com/en/img/featurePage1/performanceImage.png

Postman, J. (2011, September 2). Do QR codes have to be black and white? [Blog post]. Retrieved May 28, 2016, from https://www.quora.com/Do-QR-codes-have-to-be-black-and-white.

QR Code Generator from the ZXing Project. (n.d.). Retrieved March 15, 2016 from https://zxing.appspot.com/generator

QRcode.com. Denso Wave, the Creator of QR Codes. (n.d). Retrieved November 20, 2015 from http://www.qrcode.com/en

QRstuff.com. (n.d.). Retrieved May 18, 2016, from https://www.qrstuff.com/newaccount

QRZnow.com. (n.d.). Retrieved June 21, 2016, from http://qrznow.com/li-fi-is-a-bidirectional-high-speed-and-fully-networked-wireless-communication-technology/

Reed-Solomon codes for coders. (January 14, 2016). Retrieved May 20, 2016 from https://en.wikiversity.org/wiki/Reed%E2%80%93Solomon_codes_for_coders

Richter, S. P. (2013, June). *Digital semaphore: tactical implications of QR code optical signaling for fleet communications*. (Master's thesis, Naval Postgraduate School, Monterey, CA). Retrieved from Calhoun http://hdl.handle.net/10945/34727

Risselada, H., Verhoef, P. C. , and Bijmolt, T. H. A. (2014) Dynamic effects of social influence and Direct Marketing on the adoption of high-technology products. *Journal of Marketing: March 2014, Vol. 78, No. 2*. p. 52–68.

Singer, N. (2016, January 29). With a few bits of data, researchers identify 'anonymous' people [Blog post]. Retrieved from http://bits.blogs.nytimes.com/2015/01/29/with-a-few-bits-of-data-researchers-identify-anonymous-people/

Smith, E. A. (2006). *Complexity, networking, and effects-based approaches to operations*. Washington, DC: CCRP Publications.

Tactical QR Code Communication. (n.d.) [Video file]. Retrieved from http://www.nps.edu/Video/UVE/Embedder/Flash.aspx?app=MOVES&media=QRCodeDemonstration.mp4&media_webm=&splash=http://fmsweb.nps.edu/stills/MOVES/QRsplashimage.jpg&usessl=no&width=768&height=432&referer=&useautoplay=true

Tsonev, D.; Videv, S.; Haas, H. (2013, December 18). Light fidelity (Li-Fi): Towards all-optical networking. *Proc. SPIE 9007 (Broadband Access Communication Technologies VIII)*. doi:10.1117/12.2044649

Tutorial. (2012). Retrieved May 12, 2016 from http://iqr.hrubasko.com/tutorials.

Using Light-Emitting Diodes. (2013, December 31). Retrieved from http://web.archive.org/web/20090419162319/http://www2.eere.energy.gov/buildings/ssl/using_leds.html

U.S. Joint Chiefs of Staff. (2012). *Information Operations* (JP 3–13). Washington, DC: Author.

U.S. Marine Corps. (2010). *Marine Air-Ground Task Force Information Operations* (MCWP 3–40.4). Quantico, VA: Author.

U.S. Marine Corps. (2013). *Marine Corps Information Operations* (MCO 3120.10A.) Quantico, VA: Author.

U.S. Marine Corps. (2005). *Warfighting* (MCDP-1). Quantico, VA: Author.

Villapaz, L. (2014, January 24). Super Bowl Ads From 1979–2013: The evolution of advertising trends from long narratives to viral marketing [Article]. Retrieved from http://www.ibtimes.com/super-bowl-ads-1979-2013-evolution-advertising-trends-long-narratives-viral-marketing-1547294

Visible Light Communications. (n.d.). Retrieved May 7, 2016, from http://visiblelightcomm.com

Wikimedia Commons. 1940s illustration of Paul Revere's ride. (n.d.) [Picture]. Retrieved on June 13, 2016 from https://commons.wikimedia.org/w/index.php?curid=3519673

Wikipedia: General Disclaimer. (n.d.). In Wikipedia. Retrieved May 6, 2016, from http://en.wikipedia.org/wiki/Wikipedia:General_disclaimer

Wyatt, T. (2016, February 2016). Network Optional Warfare. Retrieved on June 7, 2016 from https://wiki.nps.edu/display/NOW/Network+Optional+Warfare

Zhao, Y., Yin, X., and Chen, Z. (2011, October 28). Recommendation advertising method based on behavior retargeting. *Proc. SPIE 8205, 2011 International Conference on Photonics, 3D-Imaging, and Visualization, 82052D*. doi:10.1117/12.906090

PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California